BIOLOGICAL ESCAPEMENT GOAL FOR CHUM SALMON IN SUBDISTRICT ONE OF NORTON SOUND

By:

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EXECUTIVE SUMMARY

Available information was assembled concerning estimated escapements, estimated harvests and estimated age compositions of chum salmon *Oncorhynchus keta* returning to Subdistrict One of Norton Sound, the Nome Subdistrict, to estimate the maximum sustained yield escapement goal. Nine chum salmon producing streams are tributary to the Nome Subdistrict: the Sinuk River, the Nome River, the Bonanza River, the Snake River, the Solomon River, the Flambeau River, the Eldorado River, the Penny River, and the Cripple River. A tagging study conducted in the late 1970's found that catches of chum salmon in the Nome Subdistrict are primarily of chum salmon of local indigenous origin.

A major portion of the analysis included in this report is the development of total escapement estimates of chum salmon for the years 1974-2000 in the nine tributary streams (243 annual estimates – 9 streams x 27 years). The first effort along this line was a careful analysis of available total enumeration estimates of chum salmon escapements in the nine tributary streams and a careful examination of chum salmon survey data available for these streams as recorded in the *Norton Sound and Kotzebue Stream Survey Catalogue*. The Nome River chum salmon escapement has been enumerated by tower or weir since 1993 (8 annual estimates), however, ancillary information indicates that the total counts in 1993 and in 1996 were not accurate and should not be used. Surveys of the Nome River escapement of chum salmon were available for each of the years with total escapement estimates providing a series of annual expansion estimates. The Snake River chum salmon escapement has been enumerated by tower since 1995 (6 annual estimates), however, surveys of these escapements were only made in 1996 and 1998 thus providing two years of expansion estimates. The Eldorado River chum salmon escapement has been enumerated by tower since 1995 (6 annual estimates), however, questions concerning the 1995 and 1996 estimates prevented their use in development of an overall expansion estimate. Surveys of the Eldorado River escapement of chum salmon were available for the years 1997, 1999, and 2000, thus providing three years of expansion estimates. Thus, 18 stream by year cells (7.4% of the total) were filled with total escapement estimates from direct on-the-grounds activities leaving the remaining 225 stream by year cells for alternate methodology (92.6%).

The direct expansion data from the 1994, 1995, and 1997-2000 Nome River, the 1996 and 1998 Snake River, and the 1997, 1999 and 2000 Eldorado River were analyzed. Data including the survey count of chum salmon, date of survey, rating of survey, and whether the runs were considered early, normal, or late, were analyzed with multiple regression techniques to develop an appropriate estimator for the total enumeration counts. Of the four possible variables, only the survey count was statistically significant. Because the residuals indicated that error was log-normal, a log-transformed linear model was fit to the data and the multiple R squared for the fit of the model to the 14 data points was 0.68. The predictive equation developed was total escapement of chum salmon = 48.059*survey count of chum salmon raised to the 0.657142 power. Direct application of this expansion formula to the data set from which it was derived indicated that average absolute percent error associated with the methodology was 33% and the expansion application approach is termed method two. This method two approach was used to expand survey counts of chum salmon in the nine tributary systems during years when tower or weir counts were unavailable given three application rules. First, survey rating had to be a 1 (good) or 2 (fair) because all survey ratings in the data used to develop the relationship were 1s or 2s. Second, only surveys that took place after July 7 were expanded in this way because the data used to develop the relationship all took place after July 7. Third, this method was not used when the pink to chum ratios in the survey exceeded 100 and the chum counts seemed to be overly high or low. This last rule was used as it seemed that the presence of relatively large numbers of pink salmon during a survey could bias the accuracy of the chum salmon count. Use of these three application rules resulted in an additional 18 years of total chum salmon escapement estimates for the Sinuk River, 17 years for the Nome River, 18 years for the Bonanza River, 9 years for the Snake River, 21 years for the Solomon, 23 years for the Flambeau, 19 years for the Eldorado, 5 years for the Penny River, and 6 years for the Cripple River. Thus another 136 stream by year cells were filled (56.0%).

The next step was to run statistical corelations and regressions between the expanded total escapement estimates to determine if escapement patterns were similar; the approach was termed method three. First, a comparison of total escapement patterns for the Flambeau and Eldorado Rivers was made because they are in the same primary drainage system of Norton Sound and logic dictated that they should be related. The correlation was 0.704 and it was significant at the 0.005 level. A regression of the two data sets resulted in the relationship: Flambeau total chum escapement = 0.661 * Eldorado total chum escapement. Average absolute percent error associated with this estimation procedure was 89% and it was used to estimate three of the annual Flambeau total escapement estimates. The reverse equation was used to estimate one Eldorado River chum salmon total escapements and the average absolute percent error associated with the procedure was 60%. Next, the correlation between the Nome and Solomon rivers chum salmon total escapements was calculated at 0.808, significant at the 0.005 level. A regression of these two data sets resulted in the relationship: Nome total escapement = Solomon total escapement/0.368. This method three approach was used to fill out two Nome River stream by year cells and had an associated average absolute percent error of 56%. The reverse equation (Solomon total escapement = 0.368*Nome total escapement) was used to fill out four Solomon stream by year cells and had an associated average absolute percent error of 56%. The next step was to complete the Bonanza data set. The correlation between the Bonanza and combined Flambeau-Eldorado was 0.597, significant at the 0.01 level. The relationship developed was Bonanza total escapement = 0.198*Flambeau-Eldorado total and it was used to fill in nine stream by year cells with an associated average absolute percent error of 48%. The last method three analysis was the relationship between total estimated escapements of chum salmon in the Sinuk River and the Bonanza River (correlation = 0.487, significant at the 0.025 level, Sinuk total = 1.476*Bonanza Total). This method three approach was used to fill in nine stream by year cells for the Sinuk River chum salmon escapements with an associated average absolute percent error of 48%. Method three approaches were only used for the Sinuk, Nome, Bonanza, Solomon, Flambeau, and Eldorado river chum salmon escapements and in total, the method three approach was used to fill in 34 stream by year cells (14.0%).

A different approach was used for the Snake, Penny and Cripple rivers because, Snake River escapements were not significantly correlated with the others and the total escapement data bases available for the Penny and Cripple Rivers were too short to develop meaningful correlations. Estimates of the total escapement in the Snake River were available for the years 1977, 1978, 1985-1987, and 1991-2000 and those estimates represented 7.6% of the total escapements of chum salmon estimated for the Sinuk, Nome, Bonanza, Solomon, Flambeau, and Eldorado rivers. The value of 7.6% was used as a constant coupled with the sum of the other escapements to estimate annual values for the Snake River chum escapements in the years 1974-1976, 1979-1984, and 1988-1990 thus filling in 12 of the stream by year cells. This methodology was termed method four and was also used to fill out estimates for the Penny and Cripple Rivers with a slight modification. The modification was to include the Snake River escapements with the other six streams before estimating the total. Total escapement estimates available for 1985, 1987, 1998 and 1999 Penny River escapements indicated that Penny River escapements represented, on average 1.8% of the sum of the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, and

Eldorado total escapements. Use of this value as a constant provided a means of filling in 22 of the stream by year cells, with an associated average absolute percent error of 10%. Total escapement estimates available for 1983, 1985, 1987, and 1997 Cripple River escapements indicated that Cripple River escapements represented, on average 2.2% of the sum for the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, and Eldorado rivers. Use of this value as a constant provided a means of filling in 21 of the stream by year cells, with an associated average absolute percent error of 19%. Thus, the method four approach was used for 55 or 22.6% of the total stream by year estimate procedures.

Once these 243 stream by year cells were estimated, total summed escapement in all nine streams by year resulted in estimates of the annual escapement of chum salmon in the Nome Subdistrict of Norton Sound from 1974-2000, these values ranged from 12,312 chums in 1989 to 92,107 chums in 1995. Annual commercial catch and subsistence catch estimates for the Nome Subdistrict were added to the escapement sums to estimate total runs to the Nome Subdistrict from 1974-2000 and these values ranged from 16,485 chums in 1989 to 113,929 chums in 1981. Annual exploitations of Nome Subdistrict chum salmon populations from 1974-2000 ranged from 2% in 1999 and 2000 to 41% in 1979, averaging 19% across the 27-year period.

Annual age composition samples collected from the Nome Subdistrict of Norton Sound since 1974 amount to 173 chums aged from the 1993 Nome River escapement and 48 chums aged from the 1995 Nome River escapement. Most aged fish were either age-4 or age-5. Because age data for chum salmon in this area of Alaska is so limited, the simple assumption of 50% age-4 and 50% age-5 fish was made and applied to all years in the data set. This age composition assumption coupled with the estimated total runs from 1974-2000 was used to develop a brood table consisting of estimated escapements and estimated resultant age-specific recruits from these escapements.

An estimated spawner-recruit relationship based upon the estimated escapements of chum salmon in the years 1974-1995 and recruits resulting from these escapements 4 and 5 years later was developed. Residuals from the fit of the standard Ricker model were significantly auto-correlated at a lag of one generation. The dampened oscillation in the auto-correlation function beyond that lag and the lack of significance in the partial auto-correlation function indicated an auto-regressive process. Hence, Ricker's linearized production model was modified to include an auto-regressive parameter and maximum likelihood estimates of parameters were developed. The spawner-recruit relationship was used to estimate the summed number of chum salmon spawning in the nine chum salmon producing streams of the Nome Subdistrict that would, on average, provide for maximum sustained yield in Nome Subdistrict fisheries (S_{MSY}). The estimate so derived was a total escapement of 22,976 chum salmon. A bootstrap procedure was used to estimate precision of the estimate and to evaluate potential bias; 90% confidence interval for the estimate of S_{MSY} was thus estimated at 20,905 to 26,893 and indicated bias was low at 2.9%. The point value of 22,976 chum salmon was initially converted into a suggested biological escapement goal range of 18,000 to 36,000. Maximum sustained yield of chum salmon in the Nome Subdistrict was estimated as 33,200 chum salmon per year.

Expansion of the existing Nome Subdistrict chum salmon escapement goals based upon escapement averaging methodology for chum salmon returning to the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, and Eldorado Rivers indicated that the existing goals represented 46,412 total spawners if individual stream goals are converted to totals and then summed. This value is over two-fold the estimated S_{MSY} derived from the analysis discussed above. Discussions amongst members of the AYK biological escapement goal (BEG) committee resulted in a consensus that although the existing goals were likely too high, uncertainty in the data used to develop the analysis should temper complete acceptance of the indicated S_{MSY} derived from the analysis. Of particular concern is the fact that total escapements for the majority of the nine spawning populations during the majority of the years was not directly estimated from on-the-grounds activities but from expansions of aerial surveys or other methods. This uncertainty in data integral to the existing analysis led to extensive discussions amongst members of the AYK BEG committee. This uncertainty also led to three ancillary analyses being developed, each included as an appendix to this report.

After extensive discussion, the AYK BEG committee reached consensus that although many of the estimates associated with the reconstructed runs were uncertain, replacement escapement was likely about 58,000 total chum salmon and an appropriate S_{MSY} was about half this equilibrium escapement level or about 29,000 total chum salmon. This approach was based upon theoretical considerations and the assumption that the productivity of the Nome Subdistrict chum salmon stock was near the lowest observed for a salmon population. It should be pointed out that this methodology is more conservative (more restrictive) if adopted by ADF&G in the sense that the fishery will be less likely to over-fish. And, the method is more likely to exert a cost to fisheries than is the case for the initial approach.

The subsequent recommended range for S_{MSY} was a deliberate process of including the approximate S_{MSY} value obtained earlier as the lower bound or about 23,000 total chum salmon. The difference between that value and the value of 29,000 for a point estimate, or a difference of 6,000 chum salmon, was added to the point value to derive an upper estimate of 35,000 total chum salmon. Thus the consensus reached by the AYK BEG committee was a point estimate for S_{MSY} of **29,000** total chum salmon with a **recommended biological escapement goal range of 23,000 to 35,000 total chum salmon**. These values are judged by the AYK BEG committee to be the best available scientific estimates of S_{MSY} for the Nome Subdistrict of Norton Sound.

Two technical reviews of a draft of this report took place. Review comments are addressed within the report.

Examination of past escapement trends indicates that the Nome Subdistrict chum salmon stocks appear healthy with 22% of the escapements since 1974 being within the recommended range, 59% being above the recommended range and only 19% of the escapements being less than the recommended range. In very recent years, only the 1999 escapement that was estimated to have totaled 17,544 fish failed to reach the biological escapement goal recommended in this report. A similar evaluation on a stream by stream basis for escapements since 1990 revealed that most individual stream escapements have either been in the recommended range or have exceeded the recommended range with 1999 being the year that most often fell short of suggested target escapement levels.

Recommendations concerning improved stock assessment of chum salmon in the Nome Subdistrict of Norton Sound are provided in this report, including the recommendation to initiate additional on the grounds total enumeration of chum salmon escapements and improved age composition sampling. Based upon the analysis discussed above, the AYK BEG committee recommends that the following biological escapement goal be formally adopted by the Alaska Department of Fish and Game.

> **Nome Subdistrict of Norton Sound: 23,000 to 35,000 Total Chum Salmon in the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, Eldorado, Penny, and Cripple rivers.**

Escapement targets for seven of the nine streams that produce chum salmon in the Nome Subdistrict of Norton Sound are defined for two purposes. First, to assist fishery managers in achieving the recommended Nome Subdistrict biological escapement goal, and second to assist fishery managers in regulating in-river harvests of chum salmon. These recommended annual target total escapements are:

Sinuk River: 4,000 to 6,200 total escapement
Nome River: 2,900 to 4,300 total escapement
Bonanza River: 2,300 to 3,400 total escapement
Snake River: 1,600 to 2,500 total escapement
Solomon River: 1,100 to 1,600 total escapement
Flambeau River: 4,100 to 6,300 total escapement
Eldorado River: 6,000 to 9,200 total escapement

It should be noted that there is no convenient method that puts these total target escapement goals into aerial survey units. If the stocks above are assessed by aerial surveys, the index counts can be expanded with methods provided in this report into total escapement estimates. These subsequent total escapement estimates can then be compared to the above listed total target escapement goals.

KEY WORDS: chum salmon, *Oncorhynchus keta*, Sinuk River, Nome River, Bonanza River, Snake River, Solomon River, Flambeau River, Eldorado River, Penny River, Cripple River, Norton Sound, Nome Subdistrict, brood table, biological escapement goal, maximum sustained yield, spawner-recruit relationship

INTRODUCTION

The Norton Sound Salmon District consists of all waters between Cape Douglas in the north and Point Romanof Light in the south. The district is divided into six subdistricts: Subdistrict 1, Nome; Subdistrict 2, Golovin; Subdistrict 3, Moses Point; Subdistrict 4, Norton Bay, Subdistrict 5, Shaktoolik; and Subdistrict 6, Unalakleet. Each of these subdistricts has at least one major salmon-producing stream. Subdistrict boundaries were developed to facilitate management of individual salmon stocks. Gaudet and Schaefer (1982) reported on tagging studies conducted by ADF&G in Norton Sound in 1978 and 1979. Gaudet and Schaefer (1982) concluded that in the Nome, Golovin, Moses Point, and Norton Bay Subdistricts harvests are of salmon that originated in the subdistrict, whereas, in the Shaktoolik and Unalakleet Subdistricts, harvests were composed of mixed stocks including fish bound for the Yukon River.

Since 1974, the Nome Subdistrict of Norton Sound has supported an important fishery with commercial catches as high as 18,666 chum salmon in 1981 and subsistence catches as high as 12,192 chum salmon in 1977. Nine streams tributary to the Nome Subdistrict support spawning populations of chum salmon, the Sinuk River, the Nome River, the Bonanza River, the Snake River, the Solomon River, the Flambeau River, the Eldorado River, the Penny River, and the Cripple River. Since 1993, towers or weirs have been used to estimate total chum salmon spawners in the Nome River, while towers have been in place in the Snake River since 1995 and in the Eldorado River since 1995. Alaska Department of Fish and Game (ADF&G) staff attempt to survey the nine streams on an annual basis to index chum salmon spawning abundance.

The ADF&G has attempted to manage the salmon fisheries in the Nome Subdistrict over the past few decades with the dual goal of maintaining important fisheries while at the same time achieving desired escapements. Escapement objectives for Nome Subdistrict chum salmon stocks have been in effect over the past 20 years. Buklis (1993) lists the ADF&G Nome Subdistrict chum salmon escapement goals as:

"4,500 aerial survey count for the Sinuk River
2,000 aerial survey count for the Nome River
1,500 aerial survey count for the Bonanza River
1,000 aerial survey count for the Snake River
550 aerial survey count for the Solomon River
3,250 aerial survey count for the Flambeau River
5,250 aerial survey count for the Eldorado River"

Buklis (1993) provides information concerning the methodology used to set these goals as well as historical background concerning the goals.

"Peak annual aerial survey counts were averaged for years that produced average or better returns. Surveys that were incomplete or that were conducted under poor survey conditions were excluded. At least five data points were used to calculate these averages."

"The chum salmon escapement goals for the Nome Flambeau, Eldorado and Bonanza Rivers were in place prior to the 1982 season. The goal for the Sinuk River was in place prior to the 1984 season. The Snake and Solomon River goals were in place prior to the 1991 season."

Fair et al (1999) made recommendations concerning updating of the Nome Subdistrict chum salmon biological escapement goals (BEG's). Lower point goal changes were recommended for the Bonanza River, the Solomon River, the Flambeau River and the Eldorado River and they recommended expressing the BEGs as ranges based upon the Eggers' (1993) procedure. Specific recommendations made by Fair et al (1999) follow (all are in units of aerial surveys):

"Sinuk River – Point Goal = 4,500, Recommended BEG = 3,600 to 7,200
Nome River – Point Goal = 2,000, Recommended BEG = 1,600 to 3,200
Bonanza River – Point Goal = 1,200, Recommended BEG = 1,000 to 1,900
Snake River – Point Goal = 1,000, Recommended BEG = 800 to 1,600
Solomon River – Point Goal = 350, Recommended BEG = 300 to 550
Eldorado and Flambeau Combined – Point Goal = 6,500, Recommended BEG = 5,200 to 10,400"

Methodology employed in the Fair et al (1999) report was similar to the approach documented by Buklis (1993) and was based upon escapement averaging. The major difference was that additional years of aerial survey data were available and the newer average escapements were different than the initial escapement averages documented by Buklis (1993).

This report is written to document current analyses relevant to developing a stock-recruit relationship for the Nome Subdistrict chum salmon stock and to make recommendations to ADF&G as to an appropriate biological escapement goal for this important stock of Norton Sound chum salmon.

NOME SUBDISTRICT CHUM SALMON ESCAPEMENTS

The most significant challenge in reconstructing the Nome Subdistrict chum salmon runs and developing a stock-recruit relationship for the Nome Subdistrict chum salmon stock is development of annual total escapement estimates for the nine contributing spawning populations. The years 1974-2000 were included in the present analysis and hence 243 individual spawning escapement estimates were needed (9 streams for 27 years each). Four general methodologies were used to address this challenge (Tables 1-9). First, those total abundance estimates that were available were identified and used when believed to have been mostly successful at enumerating total escapements. A total of 18 estimates were derived with this first method (7.4% of the total estimates), estimates of measurement errors associated with these total enumeration estimates are unknown, but assumed small. Second, a generalized expansion factor was developed based upon the paired data set of complete escapement enumeration estimates and surveys of those escapements. A total of 136 escapement estimates were developed with the method two approach (56.0% of the total estimates). Associated absolute average percent error with the method two approach was estimated at 33% (Table 10). Third, a series of correlations and regressions of total escapement estimates for paired streams were developed and when significant relationships were identified, they were used to estimate one total escapement estimate from that of another stream in the same year. A total of 34 escapement estimates were developed with the method three approach (14.0%). Average absolute percent errors associated with method three estimates ranged from 48% for the Sinuk and Bonanza estimates to 89% for the Flambeau estimates (Tables 11-16). Fourth, the percent of total escapement counted in the Snake (7.3%) as contrasted to the total in the Sinuk, Nome, Bonanza, Solomon, Flambeau and Eldorado during the years when total escapement estimates were available for all systems led to the use of 7.6% as a constant to generate Snake River escapement estimates in other years. In a generally similar approach, a constant of 1.8% for the Penny and 2.2% for the Cripple Rivers led to use of those values as constants for those two streams in other years. This method four approach was used to generate 55 or 22.6% of the total escapement estimates). Average absolute percent errors associated with method four estimates ranged from 10% for the Penny River estimates to 40% for the Snake River estimates (Tables 17-19). Details concerning these methodologies are provided in the following sections.

Method One

A tower was used in the Nome River from 1993-1995 and a weir was used from 1996-2000 to assist in the total enumeration of the chum salmon escapements in those years. Tower estimates of the total escapement of Nome River chum salmon in 1993, 1994, and 1995 were 1,566, 2,893, and 5,092, respectively. Weir counts of chum salmon from 1996-2000 were 3,339, 5,131, 976, 1,048, and 4,051, respectively. However, Fair et al (1999) state that the 1993 tower assessment began after much of the run had passed upstream. Fair et al (1999) also state the 1996 weir count to have been unreliable, although they do not state the specific reason. Good quality surveys were made of the Nome River chum salmon escapements in both 1993 and 1996, and I decided to use survey expansions for these years rather than the suspect total enumeration estimates. The 1993 and 1996 data were also censured from the method two data. Therefore, the 1994, 1995, and 1997-2000 total estimates (6 annual estimates) provided from the on the grounds assessment projects were considered to be valid estimates of total Nome River chum salmon escapements (Table 2). The tower and weir escapement assessment methodologies used for Nome River chum salmon are believed to have been rigorous and without bias. It seems likely to me that the coefficients of variation associated with the annual escapement assessments are likely less than 10%, but that is based on my opinion, not on sampling information. If I am correct, measurement errors associated with these six escapement estimates are minor.

A tower has been in place to assist with total enumeration of chum salmon escapements in the Snake River since 1995. Estimates of total escapement from 1995-2000 for Snake River chum salmon were 4,393, 2,772, 6,184, 11,067, 484, and 1,400, respectively, and all six estimates were considered as valid total estimates for use in this report (Table 4). The tower escapement assessment methodologies used for Snake River chum salmon are believed to have been rigorous and without bias. It seems likely to me that the coefficients of variation associated with the annual Snake River escapement assessments are likely less than 10% and that measurement errors associated with these six escapement estimates are minor.

A tower has been in place to assist with total enumeration of chum salmon escapements in the Eldorado River since 1995. Estimates of total escapement from 1995-2000 for Eldorado River chum salmon were 39,867, 12,655, 14,302, 13,808, 4,218, and 10,604, respectively (Table 7). Fair et al (1999) indicate unspecified problems were encountered during the 1995 and 1996 Eldorado tower counting operations, however, I elected to use the 1995 and 1996 counting tower estimates of total escapement rather than rely on an alternate method of estimating total escapement. These years were, however, censured from the method two data. The tower escapement assessment methodologies used for Eldorado River chum salmon are believed to have been rigorous and without bias. It seems likely to me that the coefficients of variation associated with the 1997-2000 Eldorado River escapement assessments are likely less than 10% and that measurement errors associated with these four escapement estimates are minor. Based upon the Fair et al (1999) comments, escapement estimates for 1995 and 1996 have less certainty and likely have larger associated measurement errors.

Method Two

After the review of total chum salmon escapement estimates available for Nome Subdistrict streams discussed above was conducted, surveys for these same escapements were extracted from the *Norton Sound and Kotzebue Stream Survey Catalogue.* This document serves as a repository of survey data, and is maintained by ADF&G staff in Nome, Alaska. The essence of the method two approach was to expand survey counts of chum salmon in the nine tributary systems during years when tower or weir counts were unavailable using an estimated expansion factor. One survey was available for each of the three years when total escapement of Eldorado River chum salmon was estimated. Two surveys were made in 1994 and 1995 of the Nome River chum salmon escapements. One survey per year was made of the 1997-2000 Nome River chum salmon escapements. Two surveys were made of the 1996 Snake River chum salmon escapement and one survey was made of the 1998 Snake River escapement. Data recorded during surveys included the count of chum salmon, the date of the survey and the rating of the survey (1 ="good", 2 = "fair", and 3 = "poor"). An additional potential variable considered was perceived timing of the run. This variable was taken as "early timing", "normal timing", and "late timing" as determined for each year by the nearby Kwiniuk counting tower operations (data for this variable was provided by Gene Sandone, personal communication). Pertinent information for these 14 paired total escapement – survey data points are provided below:

Year	Stream	Total Enumeration	Survey Count	Rating of Survey	Date of Survey	Perceived Timing	Percent Accounted for in Survey
1997	Eldorado	14,302	5,967	1	16-Jul	Normal	42%
1999	Eldorado	4,218	1,741	2	23-Jul	Early	41%
2000	Eldorado	10,604	3,383	2	20-Jul	Early	32%
1994	Nome	2,893	345	1	14-Jul	Early	12%
1994	Nome	2,893	350	1	19-Jul	Early	12%
1995	Nome	5,092	381	2	11-Jul	Early	7%
1995	Nome	5,092	1,865	1	22-Jul	Early	37%
1997	Nome	5,131	956	2	16-Jul	Normal	19%
1998	Nome	976	335	2	20-Jul	Normal	34%
1999	Nome	1,048	375	2	23-Jul	Early	36%
2000	Nome	4,051	658	2	20-Jul	Early	16%
1996	Snake	2,772	405	1	8-Jul	Early	15%
1996	Snake	2,772	370	1	20-Jul	Early	13%
1998	Snake	11,067	2,057	2	20-Jul	Normal	19%

A multiple regression of the above data was conducted to develop a predictor of total escapement. Because plots of residuals indicated that error was log-normal for a predictive relationship, efforts concentrated on fitting the log-transformed linear model:

$$\ln(N_{yr}) = \ln(a) + b_1 \ln(S_{yr}) + b_2 \ln(D_{yr}) + b_3 \ln(Y) + b_4(R) + b_5(C_{yr}) + b_6(T_{yr}) + \varepsilon_y \quad ...\ (1)$$

where: N_{yr} is the total count at the tower or weir in year y for river r ,

S_{yr} is the count during the corresponding survey ,

D_{yr} the Julian date of the survey,

C_{yr} the perceived conditions under which the survey was conducted, and

T_{yr} the perceived timing of the run

The variables R, C, and T were treated as categorical variables. The general linear model as described above was fit with the program SYSTAT. Only the factor associated with the survey count significantly acted as a predictor even though the coefficient of determination for the overall model was 0.87. When the other factors were dropped out, the coefficient of determination dropped to 0.68, but a better and more robust model resulted. The ANOVA table for the GLM fit obtained from SYSTAT is:

Dependent Variable: LNCOUNT	N = 14	Multiple R = 0.826	Squared Multiple R = 0.6812			
Adjusted Squared Multiple R = 0.655			Standard Error of Estimate = 0.462			
Effect	Coefficient	Std. Error	Std. Coef.	Tolerance	t	P(2 tail)
Constant	3.87243	0.88011	0.00000		4.39992	0.00087
LNSURVEY	0.65714	0.12965	0.82560	1.00E+00	5.06863	0.00028
Effect	Coefficient		95% Lower		95% Upper	
Constant	3.87243		1.95482		5.79004	
LNSURVEY	0.65714		0.37466		0.93962	
Analysis of Variance						
Source	Sum of Squares		df	Mean Square	F-Ratio	P
Regression	5.48937		1	5.48937	25.691	0.00027
Residual	2.56402		12	0.21367		
Durbin-Watson D Statistic = 1.746						
First Order Auto-correlation = 0.056						

A plot of the residuals of the expansion relationship developed is provided in Figure 1. The predictive equation for expansion of survey counts of chum salmon into total escapement estimates for the Nome Subdistrict stock is:

$$\hat{N}_y = (48.059)S_y^{0.657142} \quad (2)$$

The estimated average absolute percent error associated with the method two survey expansion approach was 33% with individual surveys ranging from 2% to 125% (Table 10). This method two approach was used to expand survey counts of chum salmon in the nine tributary systems during years when tower or weir counts were unavailable given three application rules. First, survey rating had to be a 1 ("good") or 2 ("fair") because all survey ratings in the data used to develop the relationship were 1s or 2s. Second, only surveys that took place after July 7 were expanded in this way because the data used to develop the relationship all took place after July 7th. Third, this method was not used when the pink to chum ratios in the survey exceeded 100 and the chum counts seemed to be overly high or low. This last rule was used, as it seemed that the presence of relatively large numbers of pink salmon during a survey could bias the accuracy of the chum salmon count during the survey. Use of these three application rules resulted in an additional 18 years of total chum salmon escapement estimates for the Sinuk River (Table 1), 17 years for the Nome River (Table 2), 18 years for the Bonanza River (Table 3), 9 years for the Snake River (Table 4), 21 years for the Solomon (Table 5), 23 years for the Flambeau (Table 6), 19 years for the Eldorado (Table 7), 5 years for the Penny River (Table 8), and 6 years for the

Cripple River (Table 9). Thus another 136 stream by year cells were filled, resulting in 56.0% of the total 243 stream by year total escapement estimates being determined with this methodology.

Method Three

The next step was to run statistical corelations and regressions between pairs of the expanded total escapement estimates to determine if escapement patterns were similar; the approach was termed method three. First, a comparison of total escapement patterns for the Flambeau and Eldorado Rivers was made because they are in the same primary drainage system of Norton Sound and logic dictated that they should be related. The correlation between the sets of total escapement estimates for the Flambeau and Eldorado River chum salmon populations was 0.704 and it was significant at the 0.005 level. A regression of the two data sets resulted in the relationship:

$$\text{Flambeau}_{\text{Total Escapement}} = 0.661 * \text{Eldorado}_{\text{Total Escapement}} \qquad (3)$$

Average absolute percent error associated with this estimation procedure was 89% (Table 15). This regression approach was used to estimate three of the annual Flambeau total escapement estimates (Table 6).

The reverse equation was used to estimate the 1975 Eldorado River chum salmon total escapement (Table 7):

$$\text{Eldorado}_{\text{Total Escapement}} = \text{Flambeau}_{\text{Total Escapement}} /0.661 \qquad (4)$$

The average absolute percent error associated with the procedure was 60% (Table 16). Once these total estimation calculations were completed, the Flambeau and Eldorado River escapement estimates were summed for comparison to other Nome Subdistrict chum salmon stock escapement patterns. And the only year remaining without total escapement estimates for the Flambeau and Eldorado Rivers was 1989.

Next a correlation matrix was calculated as follows:

Escapement Set	Sinuk	Nome	Bonanza	Snake	Solomon
Sinuk	1.000				
Nome	0.498	1.000			
Bonanza	0.544	0.380	1.000		
Snake	(0.117)	(0.288)	(0.072)	1.000	
Solomon	0.102	**0.808**	0.148	(0.019)	1.000
Flambeau/Eldorado	0.262	0.380	**0.597**	0.280	0.589

Examination of the correlation matrix revealed that the Snake River total escapement estimates were not significantly related with the escapement estimates for other streams. However, it looked as if the Nome and Solomon were well related and the Bonanza and Flambeau-Eldorado sum were well related, providing a method three basis for estimating additional total escapements in the Nome, Solomon and Bonanza Rivers. The correlation between the Nome and Solomon Rivers chum salmon total escapements was the highest in the correlation matrix and was calculated at 0.808, significant at the 0.005 level. A regression of the Nome and Solomon Rivers total escapement data sets resulted in the relationship:

$$\text{Nome}_{\text{Total Escapement}} = \text{Solomon}_{\text{Total Escapement}} / 0.368 \tag{5}$$

This method three approach was used to calculate two Nome River total escapement estimates (Table 2) and had an associated average absolute percent error of 56% (Table 12). The reverse equation was used to estimate four Solomon River total estimates (Table 5):

$$\text{Solomon}_{\text{Total Escapement}} = 0.368 * \text{Nome}_{\text{Total Escapement}} \tag{6}$$

The Solomon River chum salmon method three approach had an associated average absolute percent error of 56% (Table 14). This left only the years 1976 and 1992 in the Nome and Solomon data sets without total escapement estimates.

The next step was to complete the Bonanza data set. The correlation between the Bonanza and combined Flambeau-Eldorado total chum salmon escapement estimates was 0.597, significant at the 0.01 level. The relationship developed was:

$$\text{Bonanza}_{\text{Total Escapement}} = 0.198 * \text{Flambeau-Eldorado Summed}_{\text{Total Escapement}} \tag{7}$$

This method three relationship was used to estimate nine annual Bonanza total escapement estimates (Table 3). Associated average absolute percent error with this method three approach was estimated at 48% (Table 13). And at this point, the Bonanza total escapement data set from1974-2000 was the first Nome Subdistrict stream data set to be completely filled in.

Next, the estimation process for the remainder of the years in the data sets for the Flambeau, Eldorado, Nome, and Solomon Rivers was completed. The Nome and Solomon estimates were combined into a summed data set and a correlation matrix was calculated as follows:

Escapement Set	Sinuk	Bonanza	Snake	Flambeau-Eldorado Sum
Sinuk	1.000			
Bonanza	**0.487**	1.000		
Snake	(0.117)	(0.011)	1.000	
Flambeau-Eldorado Sum	0.262	0.716	0.280	1.000
Nome-Solomon Sum	0.399	0.298	(0.242)	**0.428**

The correlation between the Flambeau-Eldorado summed data set and the Nome-Solomon summed data set was 0.428, significant at the 0.025 level. A regression of these two data sets resulted in the relationship:

$$\text{Flambeau-Eldorado Summed}_{\text{Total Escapement}} = 2.196 * \text{Nome-Solomon Summed}_{\text{Total Escapement}} \tag{8}$$

This relationship was used to estimate the combined Flambeau-Eldorado total escapement in 1989 as 5,780 chum salmon and the earlier relationship provided a means of splitting this summed estimate into estimates of 2,300 in the Flambeau River (Table 6) and 3,480 in the Eldorado River (Table 7).

The predictive relationship for the Nome-Solomon summed escapement estimates was:

$$\text{Nome-Solomon Summed}_{\text{Total Escapement}} = \text{Flambeau-Eldorado Summed}_{\text{Total Escapement}} / 2.196 \tag{9}$$

This relationship was used to estimate the combined Nome-Solomon total escapement in 1976 and 1992 as 2,218 and 7,286 chum salmon, respectively. The earlier relationship provided a means of splitting this summed estimate into estimates of 1,621 and 5,325 for the Nome River in 1976 and 1992, respectively (Table 2). Likewise, estimates of 597 and 1,961 were developed for the Solomon River in 1976 and 1992, respectively (Table 5). And, this process completed the 1974-2000 annual escapement estimates for the Flambeau, Eldorado, Nome and Solomon Rivers.

The last method three analysis involved the relationship between total estimated escapements of chum salmon in the Sinuk River and the Bonanza River (correlation = 0.487, significant at the 0.025 level). The predictive relationship for the Sinuk River chum salmon escapement estimates was:

$$\text{Sinuk}_{\text{Total Escapement}} = 1.476 * \text{Bonanza}_{\text{Total Escapement}} \qquad (10)$$

This method three approach was used to estimate nine annual chum salmon escapement for the Sinuk River (Table 1). Associated average absolute percent error with this method three procedure was estimated at 48% (Table 11).

In summary, method three approaches were used to develop total escapement estimates for the Sinuk, Nome, Bonanza, Solomon, Flambeau, and Eldorado Rivers. In total, the method three approach was used for 34 total escapement estimates or 14.0% of the total 243 Nome Subdistrict chum salmon escapement estimates included in this report. Associated measurement errors calculated as average absolute percent error ranged from 48% for the Sinuk and Bonanza estimates to 89% for the Flambeau estimates. These measurement errors were about twice on average of the method two measurement errors.

Method Four

A different approach was used for the Snake, Penny and Cripple rivers because, Snake River escapements were not significantly correlated with the others and the total escapement data bases available for the Penny (n = 5) and Cripple (n = 6) Rivers were too short to develop meaningful correlations. Additionally, data that was available from method one and two analyses indicated that these three streams produced few chum salmon, particularly in the case of the Penny and Cripple Rivers. Given these facts, two alternatives were considered: (1) ignoring these escapements, or (2) adjusting the escapement totals and trends developed from the first six streams (Sinuk, Nome, Solomon, Bonanza, Flambeau, and Eldorado) upward by a constant value when other specific annual information was lacking. The second approach was chosen.

Estimates of the total escapement in the Snake River were available for the years 1977, 1978, 1985-1987, and 1991-2000 from method one and two analyses (Table 4). The value for 1978 was the lowest (2.1%) and 1998 the highest (40.1%). These were not included in the estimate of average proportion. For years where data were available and exclusive of 1978 and 1998, the Snake River averaged 7.6% of the total escapements of chum salmon estimated for the Sinuk, Nome, Bonanza, Solomon, Flambeau, and Eldorado Rivers. The value of 7.6% was subsequently used as a constant coupled with the sum of the other escapements (those in the Sinuk, Nome, Solomon, Bonanza, Flambeau, and Eldorado Rivers) to estimate annual values for the Snake River chum escapements in the years 1974-1976, 1979-1984, and 1988-1990, thus providing 12 of the annual escapement estimates (Table 4). Average absolute percent error associated with this method four procedure was estimated at 40% (Table 17).

The method four approach for estimating total escapements of chum salmon in the Penny and Cripple Rivers when method two estimates were not available was similar to the Snake River approach with a slight modification. The modification was that the Snake River escapements were added in with the other six streams (Sinuk, Nome, Solomon, Bonanza, Flambeau, and Eldorado) before estimating the total.

Total estimates available for 1985, 1987, 1998 and 1999 Penny River escapements indicated that Penny River escapements represented, on average 1.8% of the sum of the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, and Eldorado total escapements. The 1975 method two estimate provided a fifth estimate of 6.1% of the total, however, that value was considered to be too high and was not included in the 1.8% average value. Use of the 1.8% value as a constant provided a means of filling in 22 of the annual Penny River total escapement estimates (Table 8), with an associated average absolute percent error estimated at 10% (Table 18).

Total estimates available for 1983, 1985, 1987 and 1997 Cripple River escapements indicated that Cripple River escapements represented, on average 2.2% of the sum for the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, and Eldorado rivers. The 1991 and 1999 method two estimates provided additional estimates of 12.6% and 10.0% as values for the total, however, those values were considered to be too high and were not included in the 2.2% average value. Use of this value (2.2%) as a constant provided a means of estimating an additional 21 annual escapements for the Cripple River (Table 9), with an associated average absolute percent error estimated at 19% (Table 19).

In summary, method four procedures were used to develop total escapement estimates for the Snake, Penny and Cripple Rivers. In total, the method four approach was used for 55 total escapement estimates or 22.6% of the total 243 Nome Subdistrict chum salmon escapement estimates included in this report. Associated measurement errors calculated as average absolute percent error ranged from 10% for the Penny estimates to 40% for the Snake estimates. These measurement errors were about the same, on average, as the method two measurement errors.

Nome Subdistrict Total Escapements of Chum Salmon

A discussion of the escapement estimation procedures employed above may be helpful to the reader before proceeding further. Only a minority of total escapement estimates in this report was derived from on the grounds sampling efforts (18 of 243). And, it could be that a technical case could be made for not including some of the estimates I included or a technical case made for including a couple of others. Although these initial choices have undoubtedly influenced both the method one escapement estimates included herein and the data base for calculation of method two survey expansions, other approaches would not have changed the results substantially unless the majority of the survey expansion data base was eliminated. In other words, incorporation of one or two more data points or the removal of one or two data points would not significantly have changed the escapement magnitudes and trends developed in this report. The same goes for the method three analyses. Because the estimates I developed were based upon the pathway I took through the various correlation and regression processes, alternate pathways even if chosen carefully, could have resulted in somewhat different total escapement estimates. But again, because I used significant relationships to retain escapement magnitudes and trends, alternate pathways would have resulted in only minor changes in the overall magnitudes and trends of estimated total escapements. Lastly, the method four approach I used retained escapement trends but increased escapement magnitudes to a small extent. Again, other approaches would have influenced overall escapement magnitudes and trends only to a minor degree. Lastly, I have made efforts to provide the reader with estimates of likely sampling errors associated with the various escapement estimates I have developed so the reader can make independent judgements concerning validity of these estimates

It is important to note that the escapement estimates developed in this report are believed to be reasonable. But, just how reasonable they are cannot ever be definitely answered because for the most part, these escapements were not closely monitored, instead, a single survey or two was conducted to index escapement strength in most years for most spawning populations. The strength of the analysis in the end will not be how well I have estimated individual spawning escapements, but whether or not the escapement magnitudes and trends when combined for all nine spawning populations reflect actual run strength of the Nome Subdistrict chum salmon escapements. And, even for very recent years, this cannot be reaffirmed very well as several of the major chum salmon producing streams still do not have on the grounds stock assessment efforts in place. That said, I encourage others to develop run re-constructions for these stocks as an independent means of affirming or rejecting the overall Nome Subdistrict chum salmon historic escapement magnitudes and trends.

Total annual escapements of Nome Subdistrict chum salmon were estimated for the years 1974-2000 by summing annual chum salmon escapement estimates already described earlier in this report for the Sinuk River, the Nome River, the Bonanza River, the Snake River, the Solomon River, the Flambeau River, the Eldorado River, the Penny River and the Cripple River. Annual escapements thus estimated ranged from a low of 12,312 chum salmon for 1979 to a high of 92,107 chum salmon for 1995, averaging 43,303 chum salmon per year over the 27-year period of 1974-2000 (Table 20). Contrast in spawning escapements over this period was about 7.5-fold. This is a meaningful level of variation in annual spawning abundance. According to the CTC (1999), the following guidelines concerning contrast in spawning abundance can be used in statistical stock-recruit analyses:

> *"When estimates of spawning abundance are similar – the range is less than 4 times the smallest spawning abundance – statistical stock-recruit analysis is likely to produce a poor estimate of S_{MSY}.*
>
> *When range in spawning abundance is 4 to 8 times the smallest level, statistical stock-recruit analysis should produce better estimates of S_{MSY}, so long as measurement error is not extreme and some of the production-to-spawner ratios are below one at higher levels of spawning abundance.*
>
> *When range is more than 8, statistical analysis should produce the best estimates, so long as some of the production-to-spawner ratios are below one at higher levels of spawning abundance."*

With a contrast of spawning escapements of about 7.5-fold, the Nome Subdistrict chum salmon analysis fits into the upper part of the middle category identified by the CTC (1999) general methods. And, therefore measurement errors and production-to-spawner levels are important in determining if data will be adequate to conduct a statistical analysis. As can be found later in this report, 22 brood years of recruits are estimated and all four brood year escapements of more than 70,000 spawners failed to replace themselves. Thus, one of the criteria for the middle category is met. The other criterion (measurement error) is a more difficult problem to assess. Most of the individual stream-specific spawning escapements have average absolute percent errors of about 35% with a few ranging as low as 10% and a few ranging as high as about 90%. When these nine individual stream-specific escapement estimates are totaled it seems likely that measurement error associated with the sum will likely decrease to some extent. However, even if this is not the case, with most average percent errors estimated at about 35%, it seems very unlikely that measurement errors associated with the annual Nome Subdistrict estimates of total chum salmon escapements could be considered extreme. Given this logic, there is good reason to believe that the second condition listed by the CTC (1999) is met. Thus there are good technical reasons to believe that the Nome Subdistrict chum salmon stock-recruit analysis will lead to useable estimates of the escapement level that produces maximum sustained yield (S_{MSY}).

NOME SUBDISTRICT CHUM SALMON HARVESTS AND AGES

Commercial harvests of chum salmon in the Nome Subdistrict of Norton Sound since 1974 have ranged from a low of no fish harvested in 1990, 1991, and 1997-2000 to a high of 18,666 chum salmon harvested in 1981 (Table 20). Estimated subsistence harvests of chum salmon have ranged from a low of 183 fish harvested in 1974 to a high of 12,192 fish harvested in 1977 (Table 20). When annual estimated catches of chum salmon are added to estimated total escapements, estimated exploitation rates ranging from 2% (in 1998-2000) to 41% (in 1979) are estimated with the 27-year average since 1974 being 19% (Table 20). These are very low exploitation rates by Alaskan salmon fishery standards.

A marked paucity of age data for chum salmon sampled from catches and escapements in the Nome Subdistrict of Norton Sound exist. The only information found after extensive requests of knowledgeable staff consisted of the following data:

Sample Location	Year	Sample Size	Percent Age 3	Percent Age 4	Percent Age 5	Percent Age 6
Nome River Escapement	1993	173	0.6	36.4	60.7	2.3
Nome River Escapement	1995	48	-	29.2	70.8	-
Average		**111**	**0.3**	**32.8**	**65.8**	**1.2**

A review of other age data available for chum salmon sampled from catches and escapements in other parts of Norton Sound convinced me that it is typical to have a few more age-4 fish than age-5 fish, different than the above age compositions would indicate. Given this review, I elected to assume that Nome Subdistrict runs of chum salmon are 50% age-4 fish and 50% age-5 fish for the purposes of conducting further analysis. Undoubtedly, if appropriate sampling data were available, small portions of the runs would be comprised of age-3 fish and age-6 fish and the age composition would vary across years. However, given the paucity of available data, I believe I can do no better than assume a 50% age-4 and 50% age-5 composition across years.

Estimates of the annual total runs of Nome Subdistrict chum salmon (Table 20, column 6) were multiplied by 0.5 to estimate age-4 and age-5 recruits four and five years earlier (Table 21). The 1974-1995 brood table thus developed for the Nome Subdistrict chum salmon stock estimates that total recruits ranged from a low of 18,053 chums from the 1985 escapement of 51,313 spawners to a high of 112,462 chums from the 1976 escapement of 17,623 spawners (Table 21).

SPAWNER-RECRUIT RELATIONSHIP FOR NOME SUBDISTRICT CHUM SALMON

Once the paired data set consisting of estimated spawners and estimated recruits four and five years later was calculated (Table 21, columns 2 and 5), a spawner-recruit relationship was developed by fitting the paired data set to the following model:

$$R_y = \alpha S_y e^{-\beta S_y} \exp(\varepsilon_y) \tag{11}$$

where: R_y = estimated total recruitment by brood y;
S_y = spawning escapement that produced brood y;
α = intrinsic rate of population increase in the absence of density-dependent limitations;
β = density-dependent parameter; and
ε_y = process error with mean 0 and variance σ_ε^2.

This model, commonly referred to as a Ricker recruitment curve (Ricker 1975), has two parameters, α and β, to estimate, given a series of spawner and resultant recruitment observations or estimates. I assumed the errors were log-normal (as is common for salmon returns), resulting in the log-transformed linear equation:

$$\ln(R_y/S_y) = \ln(\alpha) - \beta S_y + \varepsilon_y \tag{12}$$

Linear regression procedures provided estimates of the intercept (ln α) and the slope (β) in equation 12. Hilborn and Walters (1992:271-2) published the following empirical approximation of the estimated spawning size that produces maximum sustained yield or MSY (S_{MSY}) as a function of estimated parameters:

$$\hat{S}_{MSY} \cong \frac{\widehat{\ln\alpha} + \hat{\sigma}_\varepsilon^2/2}{\hat{\beta}}[0.5 - 0.07(\widehat{\ln\alpha} + \hat{\sigma}_\varepsilon^2/2)] \tag{13}$$

where: $\hat{\sigma}_\varepsilon^2$ = the mean square error from the regression.

Analysis of the 1974-1995 Nome Subdistrict chum salmon spawner-recruit data with the above model resulted in a problematic residual pattern (Table 22). Residuals from the fit of the standard Ricker model were significantly auto-correlated at a lag of one generation (Figure 2). The dampened oscillation in the auto-correlation function beyond that lag and the lack of significance in the partial autocorrelation function indicated an auto-regressive process. Using the methods described in (Noakes et al. 1987) and Pankratz (1992), Ricker's linearized production model was modified to include an auto-regressive parameter ϕ_1:

$$\ln(R_y/S_y) = \ln(\alpha) - \beta S_y + a_y(1 - \phi_1 \mathrm{B})^{-1} \tag{14}$$

where B is a "back-shift" operator (when used, describes a value of a variable from the previous generation). Multiplying both sides of the equation by 1 - ϕ_1B and simplifying:

$$\ln(R_y/S_y) = (1-\phi_1)\ln(\alpha) + \phi_1 \ln(R_{y-1}/S_{y-1}) - \beta(S_y - \phi_1 S_{y-1}) + a_y \tag{15}$$

provides an auto-regressive model with estimable parameters. Maximum likelihood estimates of those parameters are provided in Table 23. Because it is involved solely in the error term in equation 12, ϕ_1 is a nuisance parameter, and therefore drops out of the first derivative of this equation. The equation to estimate S_{MSY} from the auto-regressive form of Ricker's model is the same as that derived for the standard model:

$$1 = (1 - \hat{\beta}\hat{S}_{MSY})\exp(\widehat{\ln\alpha})\exp(-\hat{\beta}\hat{S}_{MSY})\exp(\hat{\sigma}_{\varepsilon}^{2}/2) \tag{16}$$

Analysis of the Nome Subdistrict chum salmon spawner-recruit relationship (Figure 3) using the data set developed for brood years 1974-1995 with the auto-regressive form of Ricker's model resulted in an estimate of 22,976 spawners as the MSY escapement level for the Nome Subdistrict stock of chum salmon (Table 23). The spawner-recruit relationship developed estimated that maximum surplus yield from the Nome Subdistrict stock of chum salmon is 33,200 fish, on average. If the Nome Subdistrict stock of chum salmon were managed at the indicated MSY escapement level of 22,976 spawners per year, a fishery yield of 33,200 fish is estimated to be provided, on average, indefinitely. The exploitation rate in this case would be 59%. Estimated absolute average percent errors of the model averaged 32% (Table 24).

BOOTSTRAP ANALYSIS OF THE SPAWNER-RECRUIT RELATIONSHIP FOR NOME SUBDISTRICT CHUM SALMON

The estimated variance $v(\hat{S}_{MSY})$ and 90% confidence intervals for $\hat{S}_{MSY}$ were calculated through non-parametric bootstrapping of residuals from the regression (see Efron and Tibshirani 1993:111-5). Residuals were calculated as differences between observed and predicted values:

$$\zeta_y = Y_y - \hat{\mathrm{E}}[Y_y] \tag{17}$$

where: ζ_y = the residual for brood y;
Y_y = $\ln(R_y/S_y)$;
$\hat{\mathrm{E}}[Y_y]$ = the predicted value.

A new set of dependent variables was generated by sampling the residuals from the auto-regressive model:

$$\widetilde{Y}_y = \zeta_y^{*} + \hat{E}[Y_y] \tag{18}$$

where the ζ_y^{*} were drawn randomly with replacement from the original vector of the n original auto-regressive residuals $\{\zeta_y\}$ (n = the number of brood years in the analysis). In this fashion a new data set was created comprised of the original values for the independent variable (spawning abundance) and corresponding simulated values $\widetilde{Y}_y$. The $\widetilde{Y}_y$ were then regressed against the original values of the independent variables to produce a new, simulated set of parameter estimates for ln α, β, and σ_{ε}^{2}. These new parameter estimates were plugged into EQ 16 to produce a simulated estimate $\tilde{S}_{MSY}$. This process was repeated 1,000 times to produce 1,000 simulated estimates of $\tilde{S}_{MSY}$. From Efron and Tibshirani (1993:47):

$$v(\hat{S}_{MSY}) = \frac{\sum_{b=1}^{1000} (\tilde{S}_{MSY(b)} - \overline{S}_{MSY})^2}{1000-1} \tag{6}$$

where $\overline{S}_{MSY} = 1000^{-1} \sum_{b=1}^{1000} \tilde{S}_{MSY(b)}$. Ninety percent confidence intervals about $\hat{S}_{MSY}$ were estimated from the 1,000 simulations with the percentile method (Efron and Tibshirani 1993:124-126). The 1,000 values of $\tilde{S}_{MSY}$ were sorted in ascending order making the 51st and the 950th values the lower and upper bounds of a 90% confidence interval.

The mean bootstrap estimate of MSY escapement for the Nome Subdistrict stock of chum salmon using the brood year 1974-1995 data set is 23,655 spawners and the coefficient of variation for this mean statistic is 7.9% (Table 25). The 90% confidence interval for the estimated MSY escapement level for the Nome Subdistrict chum salmon stock is estimated at 20,905 to 26,893 spawners (Table 25). The bootstrap mean estimate of the MSY escapement level for Nome Subdistrict chum salmon is higher than the regression estimate of 22,976 spawners, and differs by 678 fish, indicating bias is minor at 2.9% (Table 25).

BIOLOGICAL ESCAPEMENT GOAL FOR NOME SUBDISTRICT CHUM SALMON

An initial maximum sustained yield escapement goal range was estimated using the 0.8 ($\hat{S}_{MSY}$), to 1.6 ($\hat{S}_{MSY}$) procedure of Eggers (1993). This method examined optimizing harvests over a wide range of management scenarios. Thus the initial estimate of S_{MSY} was about 23,000 total spawners in the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, Eldorado, Penny, and Cripple Rivers on an annual basis. And, the initial recommendation for a biological escapement goal for the Nome Subdistrict stock of chum salmon was 18,000 to 36,000 total spawners per year. This suggested biological escapement goal range encompassed the 90% confidence interval of MSY escapement (about 21,000 to 27,000) based on the bootstrap analysis (Table 25).

Expansion of the existing escapement goals for chum salmon returning to the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, and Eldorado Rivers as shown on page 6 of this report using EQ 2 on a stock by stock basis and then summing indicated that existing goals represented 46,412 total spawners. This value is over two-fold the estimated S_{MSY} derived from the analysis discussed in this report and this large difference was worrisome to some members of the AYK biological escapement goal (BEG) committee. Discussions amongst members of the BEG committee resulted in a consensus that although the existing goals were likely too high, uncertainty in the data used to develop the analysis should temper complete acceptance of the indicated S_{MSY} derived from the analysis. Of particular concern is the fact that total escapements for the majority of the nine spawning populations during the majority of the years was not directly estimated from on-the-grounds activities but from expansions of aerial surveys or other methods. This uncertainty in data integral to the existing analysis led to extensive discussions amongst members of the AYK BEG committee.

It should be pointed out, however, that the existing goals, which are given in aerial survey index units, are not readily converted into total escapement goals. For instance the existing goals (4,500 for the Sinuk, 2,000 for the Nome, 1,200 for the Bonanza, 1,000 for the Snake, 350 for the Solomon and 6,500 for the Flambeau-Eldorado) if first converted by EQ 2 and then summed results in a total of 46,412. On the other hand if these aerial survey unit goals are first added together and then converted by EQ 2, the result is 27,311, a number not so different than the initial estimate of about 23,000 as the estimate of S_{MSY}. Because the conversion formula that best fits existing data is an exponential expansion, it is only appropriate to use it as was the case in this report. In other words, confine it's use to expand individual annual aerial surveys into estimates of total abundance before summing to estimate Nome Subdistrict chum salmon escapements, not use it to convert existing escapement goals.

Some members of the AYK BEG committee were concerned that the Ricker alpha level estimated for this population was too high. The principle concern was uncertainty in the reconstructed chum salmon runs and in particular that the low runs appeared to be biased low. These members of the AYK BEG committee felt that this may have resulted in an overestimate of the stock's productivity resulting in an indicated S_{MSY} that was too low.

After extensive discussion, the AYK BEG committee reached consensus that although many of the estimates associated with the reconstructed runs were uncertain, replacement escapement was likely about 58,000 total chum salmon and an appropriate S_{MSY} was about half this equilibrium escapement level or about 29,000 total chum salmon. This approach was based upon an examination of Figure 11.2 in Ricker (1975) wherein the locus of S_{MSY} (in terms of a proportion of equilibrium escapement) was plotted over the range of alphas. Thus, the rational is that the S_{MSY} is about half of the equilibrium escapement and the productivity is assumed near the lowest observed for a salmon population. It should be pointed out that this methodology is more conservative (more restrictive) if adopted by ADF&G, in the sense that the fishery will be less likely to over-fish and the method is more likely to exert a cost to fisheries than was the case for the analysis based upon an estimated Ricker alpha value of 4.419 (Table 23).

The subsequent recommended range for S_{MSY} was a deliberate process of including the approximate S_{MSY} value obtained earlier as the lower bound or about 23,000 total chum salmon. The difference between that value and the value of 29,000 for a point estimate, or a difference of 6,000 chum salmon, was added to the point value to derive an upper estimate of 35,000 total chum salmon. Thus the consensus reached by the AYK BEG committee was a point estimate for S_{MSY} of **29,000** total chum salmon with a **recommended biological escapement goal range of 23,000 to 35,000 total chum salmon**. These values are judged by the committee to be the best available scientific estimates of the escapements anticipated to provide for maximum sustained yield in the Nome Subdistrict of Norton Sound.

STOCK STATUS OF NOME SUBDISTRICT CHUM SALMON GIVEN THE RECOMMENDED MSY ESCAPEMENT GOAL

From 1974 to 2000, five of the twenty-seven (19%) annual Nome Subdistrict chum salmon escapements were below the range of escapements that are currently estimated to produce maximum sustained yield fisheries in the Nome Subdistrict (Table 26). Of the twenty-two other annual total escapements, 6 (22%) were within the range of total escapements estimated to produce maximum sustained yield fisheries while the remaining 16 (59%) were above that range. This pattern is indicative of a fully healthy salmon stock. Examination of escapement patterns since 1990 shows that all but the 1990 and 1999 escapements were either within the recommended range (1 year or 9%) or they exceeded the recommended range (8 years or 73%). There was no commercial fishery in 1990 or in 1999 (Table 20). Subsistence catch in 1990 was about average at 4,246 chums while in 1999, subsistence catch was well below average and estimated to have totaled 337 chum salmon (Table 20). Hence, the lower than desired 1990 and 1999 escapements of chum salmon in the Nome Subdistrict were due to low abundance not due to over-fishing. And, the 1990 and 1999 escapements were not all that short of desired levels. The 1990 estimated total chum salmon escapement in the Nome Subdistrict was 15,375 fish, 7,625 chum salmon short of the lower bound of the recommended biological escapement goal (33% short). The 1999 estimated total chum salmon escapement in the Nome Subdistrict was 17,544, only 5,456 fish short of the lower bound of the recommended biological escapement goal (24% short). All in all, the pattern of escapements indicates that the Nome Subdistrict stock of chum salmon is fully healthy, but has been underutilized in about 59% of the years since 1974 and in about 73% of the years since 1990.

The pattern of escapements, catches and total runs of the Nome Subdistrict displays a classic case of an underutilized salmon stock (Figure 4). Small escapements have often produced large returns (Figures 3 and 4). Large escapements at best have produced medium sized runs, but usually small runs (Figures 3 and 4). And medium runs have mostly replicated themselves as medium runs, sometimes producing small runs, but never large runs (Figures 3 and 4). Increased run strength of this stock in future years will be dependent upon larger harvests and lower resultant escapements. With current exploitation patterns, the stock will continue to settle in around replacement level, pretty much the average pattern observed since 1991. To achieve large runs of chum salmon, such as occurred with brood years 1976, 1977, and 1990, escapements near the estimated MSY escapement level will be required. Although the pattern of total run strength of Nome Subdistrict chum salmon has varied since 1974, the stock shows no sign of long-term change, current run strengths are in the range of run strengths observed two decades ago. The Nome Subdistrict chum salmon stock appears healthy but underutilized.

ESCAPEMENT TARGETS FOR NOME SUBDISTRICT STREAMS AND STOCK STATUS OF THESE INDIVIDUAL SPAWNING POPULATIONS

It is beyond the scope of this report to identify scientifically defensible biological escapement goals for the nine specific streams that support spawning populations of chum salmon in the Nome Subdistrict. However, this analysis does identify total spawning target levels for seven of these nine chum salmon producing streams of the Nome Subdistrict. This can facilitate fishery management in two ways: (1) assist fishery managers in achieving the recommended overall Nome Subdistrict biological escapement goal; and, (2) assist fishery managers in regulating in-river harvests of chum salmon in these streams.

The procedure used to define target escapements for the seven chum salmon producing streams was to estimate the average portion of the total Nome Subdistrict escapement that was comprised of each of these seven spawning populations (Table 27). Further, the total target point escapements calculated in this manner were converted into a range, again using the portions of each as applied to the overall lower and upper escapement goal bounds (Table 27). For fishery mangers to use these targets for streams without total on-the-ground stock assessments, the aerial surveys will need to be converted into a total escapement estimate using EQ 2.

A comparison of these escapement targets to the escapements estimated in this report for the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, and Eldorado Rivers reveals that most escapements since 1990 have either been in the recommended range or have exceeded the recommended range (Table 28). According to this analysis, the Sinuk River and the Bonanza River chum salmon stocks have most often had escapements within or above the target recommendations while the Solomon River has most often failed to achieve the recommended target escapement level (Table 28). And review of these patterns reveals that 1999 was the year that was most often associated with a target escapement shortfall which as discussed earlier was the direct result of low abundance, not over-fishing in the Nome Subdistrict.

ANCILLARY ANALYSIS

Various ancillary analyses addressing appropriate biological escapement goals for chum salmon returning to Subdistrict One of Norton Sound were conducted as a draft of the work reported herein was being reviewed by ADF&G and other fishery scientists.

A Markovian analysis (Appendix A) indicated that returns from total escapements of chum salmon to Subdistrict One of Norton Sound in excess of 20,000 fish are relatively constant and average about 50,000 fish (Figure A-1). Markovian analysis indicated that yields are maximized for total escapements in the range of 10,000 to 20,000 fish (Figure A-2) and that such yields would average about 50,000 chum salmon per year. Escapements from 20,000 to 40,000 are estimated to produce yields of 20,000 fish and escapements in excess of 40,000 have null or negative yields. This analysis (Markovian) supports a lower biological escapement goal range than that identified and recommended in this report.

Markovian analyses was also undertaken for total returns of chum salmon to the Snake, Nome, and Eldorado-Flambeau river systems of Norton Sound. If biological escapement goals for these chum salmon populations were identified based upon Markovian analyses:

1. Target escapement goals for the Nome River population would have been under 2,500 rather than the 2,900-4,300 total fish listed in the *Recommendations* (Table A-8).

2. Target escapement goals for the Eldorado-Flambeau population would have been under 5,000 rather than the 10,100 to 15,500 total fish listed in the *Recommendations* (Table A-10).

3. Target escapement goals for the Snake River population would have been about 1,000 to 2,000 rather than the 1,600 to 2,500 total fish listed in the *Recommendations* (Table A-6).

A Ricker-type stock-recruit analysis was conducted wherein the units of measure were "good" escapement survey units (Appendix B). The analysis indicated that MSY escapement for Subdistrict One of Norton Sound was 9,442, 9,070, or 5,598 chum salmon observed in "good" escapement surveys depending upon whether the 1974-1995 data set, the 1980-1995 data set, or the 1983-1995 data set was used, respectively (Table B-9). The MSY escapement associated with the full data set of about 9,500 chum salmon in "good" aerial surveys equates to about 20,000 total chum salmon in Subdistrict One of Norton Sound spawning streams, the other estimates equate to fewer total chum salmon. This Ricker-type analysis based upon escapement survey units of measurement indicates biological escapement goals should be set at lower levels than those identified in the *Recommendations* section.

A third ancillary analysis was conducted. This analysis attempted to determine appropriate total escapement goals for chum salmon returning to the Nome, Snake, and Eldorado-Flambeau river systems of Norton Sound (Appendix C). The intent was to derive river specific goals for these three systems because total enumeration projects currently in place provide direct estimates of total escapement into these three river systems. The analyses indicated that total escapements of 1,499 chum salmon in the Snake River, 3,254 chum salmon in the Nome River, and 11,008 chum salmon in the Eldorado-Flambeau River system were MSY escapement levels. The MSY escapement levels indicated for the Nome River and for the Eldorado-Flambeau River system were within the escapement target levels identified for those systems in the *Recommendations* section of this report. The indicated MSY escapement level for the Snake River, on the other hand, was below the level identified in the *Recommendations* section.

Lastly, a member of the ADF&G BEG Committee suggested the hypothesis that a variable such as poor ocean conditions in the 1990s could have resulted in a low and continued trend of abundance (production) that was not necessarily due to escapement levels. The committee member felt that the existing analysis had not focused adequately on possible environmental and climatic effects on production, particularly in light of the relatively short database.

It is difficult to evaluate potential environmental and climatic effects on production for the chum salmon stocks of the Nome Subdistrict. This is because the production (recruitment) estimates developed in this report only encompass a 22-year period (production resulting from escapements in the years 1974-1995). And, these potential variables are difficult to assess because there are no smolt estimates available, hence oceanic survival and mortalities that took place in freshwater versus the ocean cannot be scientifically separated nor assessed. The existing analysis (returns per spawner) does not demonstrate significant production trends over the time period of data available, brood years 1974-1995, however, production during this time period was variable.

I am unsure if environmental and climatic conditions that the Nome Subdistrict chum salmon stocks have encountered in freshwater and/or during their oceanic life history stages have changed. And, I am unsure if these conditions which may have changed, have thereby resulted in significant changes in Nome Subdistrict chum salmon production. I recognize that production of Nome Subdistrict chum salmon prior to the 1974-1995 database developed in this report may have been different. However, information in this regard is sketchy and tends to be primarily of a conjecture and anecdotal nature making it difficult to conduct hypothesis tests. Further, if conditions prior to 1974 were substantially different than the conditions of the more recent period, it would make sense to manage the stocks for the current conditions not for conditions that have been different for the past 25 years. Likewise, if in the future, significant environmental and climatic conditions result in an altered productivity of these stocks, it would be prudent to alter the fishery management regimes used for these chum salmon stocks in an adaptive management framework.

In general, the ancillary analyses indicated that escapement targets and goals as defined in the *Recommendations* section are either consistent or higher than those that would have been selected if the selection was based upon methodology as described in these three appendices.

REVIEW COMMENTS AND AUTHORS RESPONSE

This and five other draft reports concerning biological escapement goals (BEGs) for salmon stocks in the Arctic-Yukon-Kuskokwim (AYK) Region of Alaska were prepared by ADF&G staff and released for public review in November and December of 2000. Two written reviews concerning the draft BEG technical reports were prepared and submitted to ADF&G. Oral and written reports concerning the six AYK BEG analysis and the two technical reviews concerning these draft analyses were submitted to the Alaska Board of Fisheries in December and January and the AYK BEG analyses became quite controversial during the January Board of Fisheries meeting. During the meeting, the Alaska Board of Fisheries formally adopted "optimal escapement goals" (OEGs) in regulation for chum salmon in the Nome River (2,900 to 4,300 total fish), Snake River 1,600 to 2,500 total fish), and Eldorado River (6,000 to 9,200 total fish). These numerical fishery management goals set in regulation by the Board of Fisheries are the same as those in the *Recommendations* section of this report. Although the Board of Fisheries adopted escapement goals for the three streams in Norton Sound with total escapement assessment programs, the regulatory agency took no action on goals for the other six streams, nor for the Nome Subdistrict as a whole. A discussion of the two reviews and the ADF&G author's response to these reviews is provided herein to better inform the reader of aspects of the technical issues involved and to provide a more complete discussion of the topic. Some of the following discussion relates to the Nome Subdistrict chum salmon analyses (the topic of this report) only in a general manner while other aspects of the discussion relate directly to the Nome Subdistrict chum salmon BEG analyses reported herein.

Mundy et al. (2001) Review

An independent scientific peer review of data and analysis included in the six draft reports was conducted at the request of ADF&G, and on January 15, 2001, this review was completed. The 42 page written review was titled "*A Preliminary Review of Western Alaskan Biological Escapement Goal Reports for the Alaska Board of Fisheries*." Members of the peer review committee were Drs. Philip R. Mundy (Chief Scientist for Exxon Valdez Oil Spill Trustee Council and chair of the committee), Milo Adkison (University of Alaska), Eric Knudsen (United States Geological Survey), Daniel Goodman (Montana State University), and Ray Hilborn (University of Washington). These scientists have published 50 or more scientific articles on the technical topic of stock-recruit analysis. In general, their review was supportive of the analyses developed by ADF&G staff, and adoption of the draft BEG goals was recommended with some revision. The committee understood the conundrum that while these draft BEG escapement goals were not perfect and should not be considered as long-term answers to the problem, they did represent a significant improvement over the existing escapement goals for these salmon stocks of the AYK region. The committee did suggest ways that various analyses could be improved in the long run to develop better escapement goals as the existing database for these stocks gains strength through time. AYK BEG authors, including myself, appreciated the committee's technical review efforts, and we appreciated the committee making positive suggestions for improvement. Hereafter this independent scientific peer review will be referred to as Mundy et al. (2001).

The Mundy et al. (2001) review includes findings, recommendations, and conclusions directed generally at all six draft BEG reports and specific comments directed at individual reports. I first address the general comments in this narrative. Findings by Mundy et al. 2001 were: "(1) *Were the analyses as presented done correctly? Yes;* (2) *Were the analyses appropriate to the available data? Yes;* and (3*) Are the estimates of S_{MSY} reasonable as long-term escapement goals? No.*"

Relative to item 3 above, Mundy et al. 2001 went on to state: "*The estimates of S_{MSY} appear reasonable short-term starting points for developing adaptive strategies for setting escapement goals appropriate to protecting the long-term interests of subsistence, commercial, and other types of uses. Any escapement goals based on these analyses must take into account the uncertainty of the S_{MSY} estimates, and they would need to be revised as soon as possible based on additional analyses and types of information described in this report. Due to a number of* *uncertainties regarding the data, the estimates of S_{MSY} are not acceptable as long-term escapement goals, nor do they meet the standards for knowledge set by the Sustainable Salmon Fishery Policy*." As author of this report and as a member of the ADF&G committee charged with developing biological escapement goals for the salmon stocks of AYK, I agree with these assessments. Further, I agree that these estimates of S_{MSY} should be used as short-term goals not as long-term goals due to uncertainty in many of the estimates used in the analyses. And, I agree that the S_{MSY} estimates should be revised as soon as possible taking into account new information as recommended in the draft reports themselves and in the Mundy et al. (2001) review document. Lastly, I agree that the standards for knowledge as discussed above are not fully met for any of the stocks described in the six draft ADF&G reports that were reviewed by Mundy et al. (2001). And until such time as a massive infusion of funding is made available for salmon stock assessment in the AYK region, this lack of basic information will unfortunately continue. I anticipate that approximately an order of magnitude of increase in funding would be needed to realistically address this problem (fully meet the data standards in the Sustainable Salmon Fishery Policy for AYK salmon fisheries).

Mundy et al. (2001) included several recommendations, including that a full detailed peer review of the six draft reports be undertaken and that all such reports be peer reviewed in the future. As authors we have extended the review period for these reports by several months, no additional written comments beyond the two reviews discussed herein have been provided. These draft reports have been reviewed more than any other draft escapement goal reports developed by ADF&G to my knowledge. Mandatory scientific peer review of future ADF&G BEG reports would require a policy decision by ADF&G's leadership.

Mundy et al. (2001) recommended use of 90% confidence intervals as BEG ranges. I disagree. Doing so would put those stocks with the least reliable data at the most risk relative to the lower bound of the range due to the fact that more uncertainty (larger variance) is associated with those stocks with poorer information. I believe a range based on the estimated productivity, a method such as that developed by the Eggers (1993) approach or the specific approach used herein is a less risky approach. An adequate management range is thus defined and those stocks with poorer information are not unduly disenfranchised. Mundy et al. (2001) suggested incorporation of additional measurement error and simulation studies. I would agree if only such information existed in the current AYK database. For instance, there are currently no estimates of the sampling variances associated with Nome, Snake, and Eldorado tower counts. I know there is measurement error in those estimates, I simply have no estimates of the magnitude, even though I believe the magnitude to be small. And, until better estimates complete with variances are made available for the basic data used in these stock-recruit analyses, it is my opinion that simulation studies will not be especially helpful, but rather will simply mirror the assumptions made in the simulation itself. Mundy et al. (2001) recommend that more precise harvest management capabilities be developed including better catch apportionment and escapement monitoring. I concur, however, again, it must be pointed out that a very large increase in funding for the salmon stock assessment program would be required to fully achieve this objective. Mundy et al. (2001) recommend that standard methods be developed for incorporation of error introduced throughout the process of preparing data for use in stock-recruitment analysis. Again I concur, but point out to achieve this objective would require a policy decision by ADF&G's leadership that in the salmon stock assessment program, variances be calculated in all cases where possible to accompany point estimates. Such a policy is in place in Sport Fish Division, but not in Commercial Fisheries Division at the current time. Mundy et al. (2001) recommend basic biological and physical databases be substantially improved and that recommendations to improve the extent and quality of necessary data as identified in the draft reports be implemented. I concur. Mundy et al. (2001) recommends the expected performance of an escapement goal or range within the management plan be evaluated in view of critical uncertainties. I believe AYK BEG report authors have done so to the extent possible and my analyses concerning "Stock Status" in this report is intended to assist the reader in this regard.

Conclusions of the Mundy et al. (2001) review include the following: "*The eventual choices of escapement goals need to take account of how (1) natural variation, (2) inherent imprecision of estimates of catch and escapement, and (3) the circumstances where some harvest occurs no matter what the run size, interact to produce actual escapements. These three factors also interact with the requirements of the management plan and the capabilities of each harvest management program to influence the escapements that reach the spawning grounds each year. ... Bear in mind that "more is not necessarily better" when it comes to salmon escapement goals. Setting the goal far too high is not precautionary, because it could lead to lost production and smaller runs. Gathering quality data at all times, and relentless periodic evaluations are the surest means of adopting escapement goals that provide sustainable use for Alaska's salmon resources*." I concur, and agree that gathering improved data concerning catches, escapements, age compositions, and stock compositions and that frequent scientific analysis of these stock-recruit data to identify appropriate escapement goals is the surest means of ADF&G fully achieving its constitutional mandate.

Mundy et al. (2001) includes comments that specifically address this Nome Subdistrict chum salmon BEG report. Mundy et al. (2001) states: "*The Ricker framework analysis appears to be the best that can be done with the data that are available. It was a very difficult task trying to estimate BEGs for these nine systems. Given the limited data, the author did a reasonable job of providing* S_{MSY} *estimates that would sustain the populations and fisheries.*" Mundy et al. (2001) goes on to say: "*The data expansions and extrapolations used to model the productivity of these nine systems are filled with uncertainty because of the large number of assumptions and scarcity of original data upon which to base the extrapolations. When 92% of the observations are estimated from a number of steps, there is a high likelihood that the estimates are inaccurate and/or biased.*" And later in the review, Mundy et al. (2001) go on to say: "*In a district with so many different spawning grounds, catch apportionment is absolutely essential to sustainable fishing.*" And, they state: "*The author makes important recommendations for data collection efforts to support improved analyses in the future and these should be fully supported. It is essential that data quality be improved for these stocks and that data be reanalyzed periodically to evaluate stock performance and adjust goals as appropriate.*"

As author of this report, as a member of the AYK BEG Committee, and as a fishery scientist, I concur with the above review comments by Mundy et al. (2001). The database for the chum salmon stocks of Subdistrict One of Norton Sound must be improved. Simple and very basic biological sampling, such as annual catch sampling, has not taken place over the past 25 years; and, these very basic sampling needs must be rectified. In my opinion, past ADF&G fishery management has reacted to the general lack of quality stock assessment information in this Subdistrict of Norton Sound by implementing very conservative fishing regimes. While these actions have certainly conserved stocks, they have also generated a serious misconception (in my opinion) of the health of the resource in this part of Alaska. Others may not agree with my view, but at the least, others should agree that the past approach of conservative fishing patterns and a poor database has resulted in a considerable controversy concerning stock health. And, others should agree that a consensus on this issue could only be achievable when an improved database considerably reduces uncertainty. Lastly, although I certainly agree that the extensive data expansions and extrapolations used in this analysis increase the likelihood that estimates are inaccurate and/or biased, the AYK BEG Committee, including myself, specifically took this concern into account when recommending a BEG for this area. The AYK BEG Committee, rather than supporting the statistically derived point goal of about 23,000, chum salmon instead have supported a point goal of 29,000 fish and that is about 6,000 fish or about 25% higher than the statistically indicated point goal. My point is that the AYK BEG Committee, including myself, explicitly took this uncertainty and concern for bias and inaccuracy into account. And, other than explicitly taking such uncertainty into account, there is little else that can be done other than to help ensure that extensive stock assessment improvements are implemented as soon as possible. This is undoubtedly why Mundy et al. (2001) state "*The Ricker framework analysis appears to be the best that can be done with the data that are available*".

The Mundy et al. (2001) review includes a section titled "*Sustainability*" that lays the premise for possible nutrient depletion in the Nome Subdistrict watersheds, possible habitat degradation from pristine levels (pre 1900's) due to mining and other human developments in the area, and possible over-fishing. As Mundy et al. (2001) states: "*It is therefore possible that the carrying capacity for these systems is greater than current data indicates*".

I believe that the question concerning nutrient depletion can only be fully addressed after a multi-year carefully conducted scientific study is completed. Further, if there has been nutrient depletion, it seems likely to me that the most appropriate remedy would be a carefully controlled and scientific fertilization program to add the needed nutrients when and where needed rather than some unspecified increase in the fishery management escapement goals for the Nome Subdistrict.

I believe the question concerning habitat degradation is another concern that can only be fully addressed with appropriate scientific study. And again, if significant habitat degradation has taken place, the habitat will need to be restored if fish production is to improve. The simple approach of putting extra fish on the spawning grounds does not solve habitat degradation problems in a watershed. Instead, the first action is to restore the habitat, then the escapements need to be increased to take advantage of the improved habitat. Within the 25-year period of this analysis, there is reason to believe the habitat has been relatively stable. And hence, reason to think the escapement goals developed are appropriate for the existing habitat. Therefore, this issue need not be a concern unless there is action taken to improve the fish production capacity of the existing habitat.

The third issue, potential over-fishing can also be addressed. The commercial fishery has harvested at most a few hundred chum salmon per year during the past 10 or so years while subsistence fishery harvests have ranged from a few hundred to a few thousand. Even with no expansions or extrapolations, the escapement surveys support the contention that exploitation has been less than 10% per year during the past 10 years. If these chum salmon stocks were depressed due to over-fishing during the 1970's and 1980's, the very low exploitations in the 1990's would have ensured significant recovery during the potential two full life cycles of that period. Yet the pattern of returns has not changed. Thus the existing data, regardless of extrapolations, do not support the hypothesis of over-fishing, but rather the opposite hypothesis, under-fishing.

Thus, although the issues raised in the "*Sustainability*" section of the Mundy et al. (2001) review are mentally stimulating, they cannot be resolved without some very serious scientific studies being implemented over a period of several years. And these issues need not cloud the issue of what are appropriate BEG goals for chum salmon in these systems over the short term (next 2-3 years). And thus again as Mundy et al. (2001) states: "*The Ricker framework analysis appears to be the best that can be done with the data that are available*".

Andersen et al. (2001) Review

Another review of the six draft ADF&G BEG reports entitled: "*Summary Review Comments*" was prepared by 12 staff from several federal agencies. Unlike Mundy et al. (2001), who largely accepted the BEGs proposed as being improvements over current goals, the federal review, hereafter referred to as Anderson et al. (2001), rejected them. Anderson et al. (2001) concentrated on statistical, not scientific issues in the six draft reports. Some of these statistical issues were identified in Mundy et al. (2001) and in the reports themselves; the rest of the federal comments were largely invalid or were valid with little relevance. Anderson et al. (2001) was silent on alternatives to the current BEGs, even though these BEGs were based in most cases on little more than averages of the same data often disparaged in Anderson et al. (2001). I concede that the quality of the data describing some of the stocks could have been better. With limited historic funding, ADF&G has not been able to completely and thoroughly assess harvests and escapements of salmon stocks in Western Alaska. With a new emphasis on the importance of stock assessment, the quality of future data should be greatly improved, and many of the statistical issues listed by Anderson et al. (2001) should be resolved. General comments by Anderson et al. (2001) follow along with my responses and other report authors responses.

Andersen et al. (2001) states: "*The importance of having precise estimates of escapements in a productivity analysis cannot be overestimated. If escapements are known with little error, uncertainty is limited to only one variable in the analysis, the harvest (return). If escapement estimates have moderate to high levels of variability, knowledge of both variables in the model is uncertain and confidence in the analysis is greatly reduced. Unfortunately, most of the subject analyses have incomplete records of total escapement, and these missing data must be estimated in order to reconstruct the entire runs.*" The first statement is overstated, the second true, the third sentence needs qualification, and the last is misleading. I won't comment further on the first two sentences. As to the third, importance of measurement error is relative to the contrast in the estimates of escapements over the years (Hilborn and Walters 1992, p. 288-9). The larger the range of estimates, the less important their measurement error. It's largely on consideration of contrast that AYK BEG report authors recommended BEGs and Mundy et al. (2001) accepted the proposed BEGs. Authors of AYK BEG reports and Mundy et al. (2001) recognized that in cases with potentially great measurement error in estimated escapements, the contrast of escapements was sufficiently large to render a scientific judgement in support of the analyses. Anderson et al. (2001) comments on contrast only to say there is more than one kind without explaining what they mean. As to the final sentence, records were incomplete only for some of the stocks analyzed in the six draft reports, not for most of the stocks. Anvik River chum salmon escapements have been monitored with "on-the grounds" methodology each year since 1972. Full and complete historic escapement records were also available for the Chena River chinook salmon stock, the Salcha River chinook salmon stock, and the Kwiniuk River chum salmon stock. When measurement error information was available from the historic AYK database, it was quantified and shown not to be a problem and was reported as such.

Andersen et al. (2001) goes on to state: "*The authors commonly report "average percent errors" as a measure of uncertainty or variability associated with the estimation. This is not a reliable method of assessing variability, especially when the relationships are based upon small sample sizes. This method produces estimates of variability that are artificially small. At a minimum, cross-validation should be used (a model is built excluding a data point, and the model is then used to estimate that data point). Standard statistical methods of assessing the variance of predictions based on linear models could also be used.*" Uncertainty in estimates of escapement was reported as "average percent error" for some of the stocks analyzed. In the others, experience has shown that uncertainty should be negligible (i.e., chum salmon escapement in the Kwiniuk River counted from a tower), or AYK BEG report authors have expressed uncertainty as estimated variances (i.e., chinook salmon in the Salcha and Chena rivers). Although I agree that "average percent error" is not the best measure of uncertainty in estimates of escapement, report authors left them as originally reported. We did so because cross-validation or predictions from linear models as proposed by Anderson et al. (2001) are flawed measures as well. The "right fix" would be to go back to the basic data (escapements, age compositions, harvest sampling efforts, etc.) and where possible, use sampling variances as estimated variances. The problem is that sampling variances were not reported or even calculated in most cases in the existing AYK database. Such statistics are currently readily available only for chinook salmon in the Salcha and Chena rivers. For many other stocks, information needed to calculate sampling variances has been lost or has never been collected. Attempts to calculate historic sampling variances are possible for some stocks, but will require considerably more time and effort than that available for these BEG analyses. My recommendation is that the databases need to be expanded to include sampling variances and that re-analysis in 2002 or 2003 take these uncertainties into account more fully than I was able to in this report. In those cases where no calculations are possible at all, only subjective judgements are currently available as to the size of uncertainty in the estimated escapements.

Andersen et al. (2001) states: "*A weakness of most of the reports is that no attempt is made to assess how uncertainty in the estimation of missing escapement data might affect confidence in the estimates of the escapement producing maximum yield (S_{MSY}). The sensitivity of the estimates of S_{MSY} to the various assumptions used to estimate escapements should be explored through careful application of simulation techniques*." The first sentence in this critique is misleading. Measurement error was assessed when that information was available from the historic database (as described above). Accuracy in estimates of S_{MSY} for the other stocks undoubtedly suffered to some degree from measurement error in estimates of escapement. But without sampling variances for estimated escapements, there is no objective way to measure the specific impact of measurement error on estimated S_{MSY}. As to the second sentence, simulation would show that the more uncertain we are in the data, the greater the negative bias in estimated S_{MSY}. Since this effect is well documented in the formal fishery science literature (see Hilborn and Walters 1992:290), we, as report authors, saw no need to confirm the effect again. Our response in the draft reports was to qualify those estimates of S_{MSY} that we believed might be biased low because of measurement error. The approach used by the AYK BEG Committee to recommending a S_{MSY} for the Nome Subdistrict chum salmon stocks typifies this approach. Note that the suggestion to simulate in Anderson et al. (2001) is not the same as the suggestion in Mundy et al. (2001). The former kind of simulation would have simulated variance for estimates of S_{MSY} as functions of estimated variances for estimated escapements. The simulation suggested by Mundy et al. (2001) would be a risk assessment for maintaining stock size as production is stochastically projected into the future. The former would be a statistical analysis while the latter would be a scientific investigation.

Andersen et al. (2001) criticized the bootstrapping approach used in the six draft reports for developing variances around estimates of S_{MSY}, pointing out that not every potential source of variation was accounted for in these bootstrap analyses. Such omissions would only be of concern if the potential sources of variation were something other than negligible. As described before, many sources of variation (measurement error) were likely negligible in their affect on estimated S_{MSY} (i.e., chum salmon counted by tower in the Kwiniuk River) or in estimates of harvest (i.e., chinook salmon in the Salcha and Chena rivers). In other cases, no estimates of variance were available. I believe that further guessing at what they might be, would have been counter productive.

Andersen et al. (2001) criticized evaluation of residuals included in the six draft reports. This criticism is unfounded. Residuals are presented to the readers, and important information gleaned from residual analysis is fully addressed in the reports.

Andersen et al. (2001) takes issue of the concept of contrast as used in the six draft reports without fully describing what a better concept would be. The definition we used is implicitly given in Hilborn and Walters (1992:288) as the range of spawning escapements over the years (or their estimates) or the variance of spawning escapements over the years (or their estimates) (as implied in Quinn and Deriso 1999:108 taken from Fuller 1987). These definitions are standard within the research done of the affect of contrast on estimates of S_{MSY}.

Andersen et al. (2001) criticizes the AYK BEG report authors sometimes use of an approximation developed by Hilborn (1985) to estimate S_{MSY} instead of the usual "exact solution" derived by solving the first derivative of the estimated stock-recruit relationship through trial and error. This is a difference without a distinction and the criticism does not affect the results. The expected difference in solutions from these two approaches would be in terms of tenths of a percent.

Andersen et al. (2001) was critical of situations where part of the time series of data was censored (chum salmon of the Kwiniuk and Tubutulik rivers). Data were censored because examination of residuals from the stock-recruit relationships estimated from the entire data series clearly showed that a significant change occurred midway through the time series. Such a change implies that earlier productivity was not representative of later productivity. What the productivity in the immediate years ahead will be I do not know, but I believe that productivity in the next three years will be more like the last three years than the productivity estimated in the early years of the full time series. For this reason, I censored the earlier data and re-estimated the stock-recruit relationship. I realize that this is a scientifically subjective decision, but so too would be to use the early data given the differential pattern of residuals.

Andersen et al. (2001) implied that recent large escapements producing poor returns are not indications of density dependence, but rather the result of reduced marine survival and criticized ADF&G analyses that fail to include factors other than escapement in the stock-recruit relationships. No estimates of the marine survival rates of smolts are available for any of the stocks in the draft reports. Without such information, no definitive scientific judgement on a marine cause behind poor returns is possible. Although reduced marine survival may have had an impact on salmon returns in recent years, there is evidence consisting of poor returns from abundant spawners, not just in recent years, but in earlier years when spawners had been abundant. In contrast, fewer spawners produced better returns in many instances scattered throughout the years for many stocks. Such a relationship is the necessary condition consistent with density-dependent survival of young salmon. That there are several brood years represented along this spectrum, as is the case with stocks of chum salmon in the Nome Subdistrict (brood years 1978, 1980, 1981, 1984, 1985, 1994, and 1995 for example), only strengthens the scientific judgements drawn.

Although the available data provides scientific evidence of density dependence, the mechanism(s) behind this density dependence is unknown. In studies of Japanese chum salmon stocks, research has shown that density does affect growth of chum salmon on the high seas, but not survival (Kaeriyame (1989 and 1998). The studied Japanese chum salmon cohorts that reared in high-density situations in the ocean returned at a smaller size than those cohorts of chum salmon that reared in low-density situations, while overall marine survival rates were not related to density. Because so few chum salmon returning to the Nome Subdistrict of Norton Sound have been sampled for age and size composition, the growth hypothesis cannot be tested for this stock of chum salmon. And, because smolt estimates for the Nome Subdistrict are not available, marine survival versus density cannot be evaluated directly. However, if this same mechanism is true for Nome Subdistrict chum salmon stocks, the observed density dependence must take place in freshwater or during their early marine phase of life history. Certainly, available spawning habitat could be a limiting factor, but whether or not, this is the density dependent mechanism involved with the Nome Subdistrict stocks is unknown. However, it appears to me that the observed numbers of spawners in Nome Subdistrict streams that have demonstrated density dependence are not excessively large. Estimated escapement contrast observed in the database is about 7.5-fold, not excessive and these factors lead me to conjecture that spawning area is likely not the density dependent factor. Given the far north location of this chum salmon stock and the likely estuarine and oceanic conditions, I would conjecture that the early marine environment and associated limiting conditions are the most likely mechanism for density dependence. However, a definitive scientific conclusion concerning the actual density dependent mechanism would require a large-scale study over a period of a number of years.

The Andersen et al. (2001) review includes some comments that specifically address this Nome Subdistrict chum salmon BEG report. Andersen et al. (2001) state: "*Local managers believe the populations were larger in the past and commercial fisheries were sustained from 1974 to 1987. In addition, a 1957 Bureau of Commercial Fisheries report estimates chum salmon subsistence harvests of the period to be approximately 66,000, much greater than harvests in years considered in this report. Nome-area chum salmon were also important for maintaining dog teams in the early part of this century. It is therefore possible that the carrying capacity for these streams is greater than the current data indicate, and that these populations are chronically depressed from long-term, relatively heavy exploitation. If so, estimates of S_{MSY}, based on* recent *data might appear reasonable, but would significantly under-estimate the habitats' actual S_{MSY}.*"

Most of this concern was addressed earlier in response to the Mundy et al. (2001) review. However, to reiterate, available data, although scanty, since the early 1970's (past 30 years) supports the hypothesis of under-fishing, not the hypothesis of over-fishing. Further, if these populations suffered from "chronic depression", why is it that the obviously low exploitations in the past decade did not lead to large increases in abundance of the areas chum salmon population? It may very well be that the current abundance (last 30 years) is less than historic abundance (pre-1970's) due to changes in habitat, nutrient availability, oceanic conditions or some other factor. If so, some progress in these specific areas is needed to increase abundance. Simply adding fish to the escapement will not improve production to the areas' chum salmon population, even the relatively poor database that is available is fully adequate to demonstrate this reality. I would agree that it is possible that potential carrying capacity may be greater, if conditions as have occurred over the past 30 years were quite different. But under conditions as have occurred over the past 30 years, it is highly unlikely that carrying capacity for these streams is greater than the current data indicate.

Andersen et al. (2001) makes a "small population" or "viable population" argument for Nome Subdistrict chum salmon stocks. They seem to be making a case that a small population of salmon either cannot support exploitation or that it can only support a lesser level of exploitation than a "larger" stock. Andersen et al. (2001) fails to support these arguments with data, examples, or literature citations and the argument being as vague as it is makes response difficult. I note that information documented in this report demonstrates tower counts as large as almost 40,000 chum salmon in the Eldorado River, one of these apparent "small populations". I would not consider the Nome Subdistrict chum salmon escapement population to be small nor do I believe the argument these reviewers put forth is a reasoned argument to reject the BEG recommendation of the AYK BEG Committee.

Andersen et al. (2001) state: "*The author's assertions (page 16) that relative errors are "about 35%" and that the "analysis will lead to useable estimates" seem overly optimistic. The uncertainty associated with the constructed escapements and returns is so large that the data series is unlikely to provide reliable trend information, let alone abundance estimates.*" This is an issue that the Andersen et al. (2001) reviewers and I will continue to disagree on. Although the database for the Nome Subdistrict chum salmon stocks is weak and needs improvement, these data are adequate to provide trend information and it is critical that ADF&G utilize the existing information to make the best decisions today. And it is critical that ADF&G strive to improve this database so that future fishery scientists and managers can make better decisions based upon improved stock assessment information. Andersen et al. (2001) did not provide an alternative database or methodology. To simply disparage the available stock assessment information for Norton Sound chum salmon is not helpful to the challenge of setting appropriate BEGs for these stocks.

Under "*Summary Comments*" Andersen et al. (2001) state: "*The foundation of this analysis is incredibly weak. Although this deficiency is acknowledged in the report, the problem is understated. Over 90% of the escapement estimates are constructed in a series of sequential extrapolations based on highly variable relationships between available sources of information. The resulting estimates have an extremely high degree of uncertainty. Given these deficiencies, the conclusion that the approach taken in the report has little scientific merit seems unavoidable.*" Again, to simply disparage the available stock assessment information for Norton Sound chum salmon and the analysis included in this report is not helpful to the challenge of setting appropriate BEGs for these stocks. What would Andersen et al. suggest, an alternate analysis, status quo, or what? While I too would like to see improved stock assessment information for Nome Subdistrict chum salmon stocks, while I too would like estimates with no associated uncertainty, I had to face reality. This is the same conundrum the AYK BEG Committee faced. The uncertainty in the estimate of S_{MSY} was explicitly taken into account in the BEG recommendation. The existing database, although not as strong as one would want, indicates existing escapement goals are about double the level they should be if MSY fisheries are to be sustained. If management is to be targeted toward use values rather than merely existence values, escapement goals must be decreased. Although uncertainty was a decision making factor, the AYK BEG Committee directly faced this challenge in its recommendation, the Andersen et al. (2001) comment on scientific merit notwithstanding.

As is obvious from reading the above passages, Anderson et al. (2001) often disparaged the quality of the data describing several of the stocks in the draft reports. While my view is not as pessimistic as theirs, I concede that the quality of the data describing some of the stocks could have been better. With limited historic funding, ADF&G has not been able to adequately assess harvests and escapements of salmon stocks in Western Alaska. Recently circumstances have improved. With a new emphasis on the importance of stock assessment, the quality of future data should be greatly improved, and many of the statistical issues listed by Anderson et al. (2001) should be resolved.

RECOMMENDATIONS

I recommend that the Alaska Department of Fish and Game formally adopt the following biological escapement goal for the Nome Subdistrict of Norton Sound.

Nome Subdistrict of Norton Sound: 23,000 to 35,000 Total Chum Salmon in the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, Eldorado, Penny, and Cripple rivers.

I recommend that ADF&G fishery managers use the following escapement <u>targets</u> to assist in achieving the overall biological escapement goal identified above and to assist with in-river management of fisheries:

Sinuk River: 4,000 to 6,200 total escapement
Nome River: 2,900 to 4,300 total escapement
Bonanza River: 2,300 to 3,400 total escapement
Snake River: 1,600 to 2,500 total escapement
Solomon River: 1,100 to 1,600 total escapement
Flambeau River: 4,100 to 6,300 total escapement
Eldorado River: 6,000 to 9,200 total escapement

I recommend that this biological escapement goal analysis be updated in three years because at that time, significantly more information will be available for further development and refinement of the overall spawner-recruit relationship. Refinement and further development of the relationship may lead to an improved escapement goal that will better result in MSY fisheries.

I recommend that the existing chum salmon stock assessment program for the Nome Subdistrict of Norton Sound be continued, advanced, and improved upon. Changes I recommend include:

1. Implement on the grounds total escapement enumeration projects for the Sinuk, Bonanza, and Flambeau chum salmon stocks. These activities could take the form of a tower project similar to the existing project on the Snake and Eldorado Rivers or a weir project similar to the existing project on the Nome River, or perhaps annual mark-recapture experiments. In any event, project goals should include the total enumeration or estimation of the Sinuk, Bonanza, and Flambeau River chum salmon escapements on an annual basis based upon sampling information. Project goals should also include estimation of the annual age composition of these escapements based upon active sampling efforts to capture, sample, and age 300 to 500 chum salmon per year.

2. Implement a much improved age composition-sampling program in the Nome Subdistrict of Norton Sound. Specifically, 300 to 500 chum salmon from the Nome, Snake, and Eldorado escapements per year should be captured, sampled and aged by the project staff manning the towers and weir. Additionally, 300-500 chum salmon per year from the commercial fishery should be sampled and aged in any year when the Nome Subdistrict commercial fishery harvests 1,000 or more chum salmon. Lastly, chum salmon caught in the Nome Subdistrict subsistence fishery should be sampled for age composition; sample sizes should be in the 300-500 range per year when catches are anticipated to exceed 1,000 chum salmon and about one half that in other years. Lastly, a crew should annually visit the Solomon, Penny, and Cripple River spawning grounds to collect age composition samples.

3. The tagging study conducted by ADF&G in the late 1970's should be repeated. It would be appropriate to reaffirm that Nome Subdistrict harvests are largely comprised of local indigenous populations of chum salmon and that local indigenous populations of Nome Subdistrict chum salmon are not caught in other Norton Sound Subdistricts in significant numbers. And, when the study is repeated, project managers should strive to achieve larger numbers of chum salmon tagged and recaptured.

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Table 1. Estimates of total escapement of chum salmon in the Sinuk River of Norton Sound from 1974-2000.

Year	Survey Count of Chum Salmon	Survey Rating & Observer	Date of Survey	Count of Pink Salmon During Survey	Pink to Chum Salmon Ratio	Chum Salmon Total Escapement Estimate	Escapement Estimate Methodology & Average Error [a]
1974	463	1-PC	9-Jul	7,766	17	2,713	Two-33%
1975	4,662	1-PC	19-Jul	5,390	1	12,375	Two-33%
1976	No survey	-	-	-	-	5,160	Three-48%
1977	5,207	1-FK	18-Jul	1,302	0	13,308	Two-33%
1978	8,756	1-FK	12-Jul	20,328	2	18,725	Two-33%
1979	No survey	-	-	-	-	1,482	Three-48%
1980	2,022	1-GS	17-Jul	199,000	98	7,147	Two-33%
1981	5,579	1-LS	10-Jul	350	0	13,925	Two-33%
1982	638	1-KF	18-Jul	148,800	233	3,517	Three-48%
1983	2,150	1-LS	12-Jul	1,975	1	7,441	Two-33%
1984	493	2-GS	27-Jul	284,400	577	6,273	Three-48%
1985	1,910	2-CL	19-Jul	1,900	1	6,885	Two-33%
1986	1,960	1-CL	22-Jul	28,690	15	7,003	Two-33%
1987	4,540	1-SM	27-Jul	30	0	12,161	Two-33%
1988	2,070	1-SM	20-Jul	4,652	2	7,258	Two-33%
1989	No survey	-	-	-	-	1,693	Three-48%
1990	95	2-FB	23-Jul	29,040	306	2,020	Three-48%
1991	5,420	1-CL	24-Jul	14,680	3	13,663	Two-33%
1992	470	3-CL	13-Jul	292,400	622	4,688	Three-48%
1993	1,570	1-CL	19-Jul	5,120	3	6,052	Two-33%
1994	1,140	1-CL	19-Jul	492,000	432	4,905	Two-33%
1995	3,100	1-CL	22-Jul	1,250	0	9,464	Two-33%
1996	1,815	1-CL	8-Jul	74,100	41	6,658	Two-33%
1997	2,975	2-FB	17-Jul	20	0	9,212	Two-33%
1998	630	2-FB	20-Jul	372,850	592	6,720	Three-48%
1999	1,697	2-FB	23-Jul	-	-	6,370	Two-33%
2000	10	1-TK	21-Jul	?	-	7,198	Three-48%
Avg	-	-	-	-	-	**7,556**	-
Min	-	-	-	-	-	**1,482**	-
Max	-	-	-	-	-	**18,725**	-

[a] Method two used the aerial survey count of chum salmon and expanded it as: $48.059*(\text{Survey Count})^{0.657142}$. Method two was only used when surveys were rated as a 1 or 2 and when the survey date was after July 7th. Method two was not used if the pink to chum ratio exceeded 100 and the chum count seemed overly high or overly low. Methodology two has an associated average absolute percent error of 33%. Method three was based upon the regression of total escapement of the Sinuk and the Bonanza chum salmon runs ($n = 18$, correlation = 0.487, significant at the 0.025 level, regression: Sinuk Total = 1.476*Bonanza total) and has an associated 48% average absolute percent error.

Table 2. Estimates of total escapement of chum salmon in the Nome River of Norton Sound from 1974-2000.

Year	Survey Count of Chum Salmon	Survey Rating & Observer	Date of Survey	Count of Pink Salmon During Survey	Pink to Chum Salmon Ratio	Chum Salmon Total Escapement Estimate	Escapement Estimate Methodology & Average Error[a]
1974	854	2-PC	24-Jul	17,830	21	4,057	Two-33%
1975	2,161	2-PC	28-Jul	44	0	7,466	Two-33%
1976	No survey	-	-	-	-	1,621	Three
1977	3,046	1-FK	18-Jul	1,726	1	9,356	Two-33%
1978	5,242	1-GS	12-Jul	34,900	7	13,366	Two-33%
1979	No survey	-	-	-	-	3,213	Three-56%
1980	7,745	1-GS	17-Jul	171,350	22	17,275	Two-33%
1981	1,035	1-LS	10-Jul	307	0	4,603	Two-33%
1982	700	1-LS	8-Jul	204,025	291	3,560	Two-33%
1983	198	1-LS	22-Jul	7,575	38	1,552	Two-33%
1984	2,084	2-RR	10-Jul	88,300	42	7,291	Two-33%
1985	1,565	1-CL	23-Jul	104	0	6,040	Two-33%
1986	920	1-CL	28-Jul	13,580	15	4,260	Two-33%
1987	1,646	1-CL	14-Jul	-	-	6,243	Two-33%
1988	889	1-SM	20-Jul	2,490	3	4,165	Two-33%
1989	No survey	-	-	-	-	1,923	Three-56%
1990	541	2-FB	23-Jul	13,085	24	3,005	Two-33%
1991	3,520	1-CL	24-Jul	4,690	1	10,289	Two-33%
1992	180	1-FB	21-Jul	255,700	1,421	5,325	Three
1993	1,520	1-CL	19-Jul	4,230	3	5,925	Two-33%
1994	345	1-FB	14-Jul	41,700	121	2,893	Tower
1995	1,865	1-CL	22-Jul	150	0	5,092	Tower
1996	799	1-CL	8-Jul	23,050	29	3,883	Two-33%
1997	956	2-FB	7/126	65	0	5,131	Weir
1998	335	2-FB	20-Jul	179,680	536	976	Weir
1999	375	2-FB	23-Jul	0	-	1,048	Weir
2000	658	2-FB	20-Jul	?	-	4,051	Weir
Avg	-	-	-	-	-	**5,319**	-
Min	-	-	-	-	-	**976**	-
Max	-	-	-	-	-	**17,275**	-

[a] Method two used the aerial survey count of chum salmon and expanded it as: $48.059*(\text{Survey Count})^{0.657142}$. Method two was only used when surveys were rated as a 1 or 2 and when the survey date was after July 7th. Although a tower was used in 1993 and a weir was used in 1996 to enumerate total Nome River chum salmon escapements, the total estimates obtained were considered unreliable and hence, method two was used. Method two was not used if the pink to chum ratio exceeded 100 and the chum count seemed overly high or overly low. Methodology two has an associated average absolute percent error of 33%. Method three was based upon the regression of total escapement of the Nome and the Solomon runs (n = 19, correlation = 0.808, significant at the 0.005 level, regression: Nome Total = Solomon total/0.368) and has an associated 56% average absolute percent error. An updated estimate of the 2000 Nome River chum escapement is 4,056, a difference of 5 fish (0.1%) from the estimate used in this report (Tom Kohler, personal communication 11/30/00).

Table 3. Estimates of total escapement of chum salmon in the Bonanza River of Norton Sound from 1974-2000.

Year	Survey Count of Chum Salmon	Survey Rating & Observer	Date of Survey	Count of Pink Salmon During Survey	Pink to Chum Salmon Ratio	Chum Salmon Total Escapement Estimate	Escapement Estimate Methodology & Average Error [a]
1974	820	?-PC	9-Jul	17,830	22	3,950	Two-33%
1975	124	2-PC	19-Jul	441	4	1,141	Two-33%
1976	681	1-PC	12-Jul	2,085	3	3,496	Two-33%
1977	990	1-FK	18-Jul	722	1	4,470	Two-33%
1978	5,984	1-FK	11-Jul	23,936	4	14,581	Two-33%
1979	102	1-FK	11-Jul	156	2	1,004	Two-33%
1980	748	2-LS	10-Jul	12,808	17	3,718	Two-33%
1981	1,864	1-LS	10-Jul	385	0	6,775	Two-33%
1982	380	1-LS	8-Jul	380	1	2,383	Two-33%
1983	723	1-LS	22-Jul	10,576	15	3,636	Two-33%
1984	No survey	-	-	-	-	4,249	Three-48%
1985	775	1-CL	23-Jul	695	1	3,806	Two-33%
1986	No survey	-	-	-	-	3,072	Three-48%
1987	190	2-CL	14-Jul	-	-	1,511	Two-33%
1988	No survey	-	-	-	-	2,441	Three-48%
1989	No survey	-	-	-	-	1,147	Three-48%
1990	No survey	-	-	-	-	1,368	Three-48%
1991	1,520	1-CL	24-Jul	2,980	2	5,925	Two-33%
1992	80	1-FB	21-Jul	79,900	999	3,176	Two-33%
1993	No survey	-	-	-	-	3,007	Three-48%
1994	No survey	-	-	-	-	5,178	Three-48%
1995	No survey	-	-	-	-	11,182	Three-48%
1996	1,980	1-CL	8-Jul	40,510	20	7,049	Two-33%
1997	881	1-FB	17-Jul	-	-	4,140	Two-33%
1998	No survey	-	-	-	-	4,552	Three-48%
1999	361	2-FB	23-Jul	0	-	2,304	Two-33%
2000	1,130	2-FB	20-Jul	?	-	4,876	Two-33%
Avg	-	-	-	-	-	**4,227**	-
Min	-	-	-	-	-	**1,004**	-
Max	-	-	-	-	-	**14,581**	-

[a] Method two used the aerial survey count of chum salmon and expanded it as: $48.059*(\text{Survey Count})^{0.657142}$. Method two was only used when surveys were rated as a 1 or 2 and when the survey date was after July 7th. Method two was not used if the pink to chum ratio exceeded 100 and the chum count seemed overly high or overly low. Methodology two has an associated average absolute percent error of 33%. Method three was based upon the regression of total escapement of the Bonanza and the combined Flambeau-Eldorado chum salmon runs (n = 17, correlation = 0.597, significant at the 0.01 level, regression: Bonanza Total = 0.198*Flambeau-Eldorado total) and has an associated 48% average absolute percent error.

Table 4. Estimates of total escapement of chum salmon in the Snake River of Norton Sound from 1974-2000.

Year	Survey Count of Chum Salmon	Survey Rating & Observer	Date of Survey	Count of Pink Salmon During Survey	Pink to Chum Salmon Ratio	Chum Salmon Total Escapement Estimate	Escapement Estimate Methodology & Average Error [a]
1974	No survey	-	-	-	-	1,605	Four-40%
1975	No survey	-	-	-	-	2,110	Four-40%
1976	No survey	-	-	-	-	1,203	Four-40%
1977	366	1-FK	18-Jul	50	0	2,325	Two-33%
1978	255	1-GS	11-Jul	1,100	4	1,833	Two-33%
1979	No survey	-	-	-	-	840	Four-40%
1980	No survey	-	-	-	-	6,218	Four-40%
1981	140	2-CL	6-Jul	5	0	5,917	Four-40%
1982	No survey	-	-	-	-	2,303	Four-40%
1983	No survey	-	-	-	-	1,853	Four-40%
1984	No survey	-	-	-	-	3,202	Four-40%
1985	1,100	1-CL	23-Jul	175	0	4,791	Two-33%
1986	415	1-CL	22-Jul	1,690	4	2,525	Two-33%
1987	267	1-CL	14-Jul	-	-	1,889	Two-33%
1988	No survey	-	-	-	-	2,030	Four-40%
1989	No survey	-	-	-	-	860	Four-40%
1990	No survey	-	-	-	-	1,050	Four-40%
1991	772	1-FB	25-Jul	190	0	3,796	Two-33%
1992	943	1-FB	21-Jul	24,700	26	4,330	Two-33%
1993	317	1-CL	19-Jul	-	-	2,115	Two-33%
1994	688	1-PV	25-Jul	26,167	38	3,519	Two-33%
1995	14	2-CL	10-Jul	-	-	4,393	Tower
1996	405	1-CL	8-Jul	350	1	2,772	Tower
1997	-	-	-	-	-	6,184	Tower
1998	2,057	2-FB	20-Jul	21,470	10	11,067	Tower
1999	400	1-CL	23-Aug	200	0	484	Tower
2000	No survey	-	-	-	-	1,400	Tower
Avg	-	-	-	-	-	**3,060**	
Min	-	-	-	-	-	**484**	
Max	-	-	-	-	-	**11,067**	

[a] Method two used the aerial survey count of chum salmon and expanded it as: $48.059*(\text{Survey Count})^{0.657142}$. Method two was only used when surveys were rated as a 1 or 2 and when the survey date was after July 7th. Method two was not used if the pink to chum ratio exceeded 100 and the chum count seemed overly high or overly low. Methodology two has an associated average absolute percent error of 33%. Method four assumed the average proportion of the Snake River escapement to the sum of the total escapements into the Sinuk, Nome, Bonanza, Solomon, Flambeau, and Eldorado rivers for the years 1977, 1978, 1985-1987, and 1991-2000 was a constant value (0.076). And, that this value could be applied to the other years in the data set. The method four procedure for the Snake River chum salmon population has an associated average absolute percent error of 40%. . An updated estimate of the 2000 Snake River chum escapement is 1,911 an increase of 511 fish (36%) from the estimate used in this report (Tom Kohler, personal communication 11/30/00).

Table 5. Estimates of total escapement of chum salmon in the Solomon River of Norton Sound from 1974-2000.

Year	Survey Count of Chum Salmon	Survey Rating & Observer	Date of Survey	Count of Pink Salmon During Survey	Pink to Chum Salmon Ratio	Chum Salmon Total Escapement Estimate	Escapement Estimate Methodology & Average Error [a]
1974	160	1-RR	8-Jul	770	5	1,350	Two-33%
1975	No survey	-	-	-	-	2,750	Three-56%
1976	No survey	-	-	-	-	597	Three
1977	275	1-FK	18-Jul	275	1	1,926	Two-33%
1978	497	1-FK	11-Jul	1,988	4	2,842	Two-33%
1979	131	1-FK	8-Jul		-	1,183	Two-33%
1980	2,600	1-GS	17-Jul	28,700	11	8,431	Two-33%
1981	No survey	-	-	-	-	1,695	Three-56%
1982	487	1-KF	18-Jul	54,100	111	2,805	Two-33%
1983	310	1-LS	22-Jul	8,180	26	2,084	Two-33%
1984	No survey	-	-	-	-	2,685	Three-56%
1985	530	1-CL	23-Jul	1,250	2	2,965	Two-33%
1986	165	1-CL	22-Jul	3,440	21	1,377	Two-33%
1987	135	1-CL	14-Jul	-	-	1,207	Two-33%
1988	25	1-CL	11-Jul	570	23	398	Two-33%
1989	60	2-CL	14-Aug	1,370	23	708	Two-33%
1990	31	2-FB	10-Jul	320	10	459	Two-33%
1991	830	1-CL	24-Jul	3,640	4	3,981	Two-33%
1992	25	1-FB	21-Jul	29,550	1,182	1,961	Three
1993	415	1-CL	19-Jul	900	2	2,525	Two-33%
1994	No survey	-	-	-	-	1,066	Three-56%
1995	315	1-CL	22-Jul	350	1	2,106	Two-33%
1996	323	1-CL	20-Jul	15,230	47	2,141	Two-33%
1997	316	1-FB	17-Jul	80	0	2,111	Two-33%
1998	90	2-FB	20-Jul	45,175	502	925	Two-33%
1999	51	2-FB	23-Jul	-	-	637	Two-33%
2000	150	2_FB	20-Jul	?	-	1,294	Two-33%
Avg	-	-	-	-	-	**2,008**	-
Min	-	-	-	-	-	**398**	-
Max	-	-	-	-	-	**8,431**	-

[a] Method two used the aerial survey count of chum salmon and expanded it as: $48.059*(\text{Survey Count})^{0.657142}$. Method two was only used when surveys were rated as a 1 or 2 and when the survey date was after July 7th. Method two was not used if the pink to chum ratio exceeded 100 and the chum count seemed overly high or overly low. Methodology two has an associated average absolute percent error of 33%. Method three was based upon the regression of total escapement of the Solomon and the Nome chum salmon runs (n = 19, correlation = 0.808, significant at the 0.005 level, regression: Solomon Total = 0.368*Nome total) and has an associated 56% average absolute percent error.

Table 6. Estimates of total escapement of chum salmon in the Flambeau River of Norton Sound from 1974-2000.

Year	Survey Count of Chum Salmon	Survey Rating & Observer	Date of Survey	Count of Pink Salmon During Survey	Pink to Chum Salmon Ratio	Chum Salmon Total Escapement Estimate	Escapement Estimate Methodology & Average Error [a]
1974	190	1-RR	8-Jul	-	0	1,511	Two-33%
1975	197	2-PC	19-Jul	1,505	8	1,547	Two-33%
1976	375	1-PC	12-Jul	1,994	5	2,362	Two-33%
1977	1,275	1-FK	18-Jul	10	0	5,279	Two-33%
1978	7,110	1-GS	12-Jul	-	0	16,331	Two-33%
1979	283	1-FK	11-Jul	291	1	1,963	Two-33%
1980	13,190	1-GS	17-Jul	16,000	1	24,511	Two-33%
1981	12,031	1-LS	10-Jul	-	0	23,073	Two-33%
1982	5,083	1-KF	18-Jul	25,001	5	13,099	Two-33%
1983	1,195	1-LS	12-Jul	85	0	5,059	Two-33%
1984	3,150	1-CL	26-Jul	20,200	6	9,564	Two-33%
1985	3,215	1-CL	19-Jul	260	0	9,694	Two-33%
1986	3,075	1-CL	22-Jul	300	0	9,414	Two-33%
1987	115	2-SM	7-Jul	-	0	1,086	Two-33%
1988	765	1-CL	12-Jul	10	0	3,774	Two-33%
1989	No survey	-	-	-	-	2,300	Three
1990	No survey	-	-	-	-	2,734	Three-89%
1991	1,564	1-FB	10-Jul	570	0	6,037	Two-33%
1992	606	1-FB	21-Jul	-	0	3,238	Two-33%
1993	1,590	1-CL	19-Jul	-	0	6,103	Two-33%
1994	4,960	1-CL	21-Jul	260	0	12,889	Two-33%
1995	7,205	1-CL	22-Jul	350	0	16,474	Two-33%
1996	5,390	1-CL	8-Jul	-	0	13,613	Two-33%
1997	905	2-CL	11-Jul	-	0	9,455	Three-89%
1998	No survey	-	-	-	-	9,129	Three-89%
1999	51	5-CL	15-Jul	-	0	637	Two-33%
2000	819	5-TK	12-Jul	?	-	3,947	Two-33%
Avg	-	-	-	-	-	**7,630**	-
Min	-	-	-	-	-	**637**	-
Max	-	-	-	-	-	**24,511**	-

[a] Method two used the aerial survey count of chum salmon and expanded it as: $48.059*(\text{Survey Count})^{0.657142}$. Method two was only used when surveys were rated as a 1 or 2 and when the survey date was after July 7th. Method two was not used if the pink to chum ratio exceeded 100 and the chum count seemed overly high or overly low. Methodology two has an associated average absolute percent error of 33%. Method three was based upon the regression of total escapement of the Flambeau and the Eldorado chum salmon runs (n = 22, correlation = 0.704, significant at the 0.005 level, regression: Flambeau Total = 0.661*Eldorado total) and has an associated 89% average absolute percent error.

Table 7. Estimates of total escapement of chum salmon in the Eldorado River of Norton Sound from 1974-2000.

Year	Survey Count of Chum Salmon	Survey Rating & Observer	Date of Survey	Count of Pink Salmon During Survey	Pink to Chum Salmon Ratio	Chum Salmon Total Escapement Estimate	Escapement Estimate Methodology & Average Error [a]
1974	2,143	1-RR	8-Jul	6,185	3	7,426	Two-33%
1975	No survey	-	-	-	-	2,340	Three-60%
1976	411	2-PC	19-Jul	1,340	3	2,509	Two-33%
1977	1,835	1-FK	18-Jul	125	0	6,706	Two-33%
1978	10,125	1-GS	12-Jul	12,800	1	20,601	Two-33%
1979	326	2-FK	8-Jul	652	2	2,154	Two-33%
1980	9,900	1-GS	17-Jul	55,520	6	20,299	Two-33%
1981	15,605	1-LS	10-Jul	495	0	27,374	Two-33%
1982	1,095	1-KF	18-Jul	163,300	149	4,776	Two-33%
1983	994	1-LS	8-Jul	-	-	4,482	Two-33%
1984	4,362	1-CL	11-Jul	35,580	8	11,846	Two-33%
1985	6,090	1-CL	19-Jul	150	0	14,750	Two-33%
1986	1,575	1-CL	22-Jul	18,200	12	6,065	Two-33%
1987	3,860	1-CL	14-Jul	-	-	10,931	Two-33%
1988	2,645	1-CL	11-Jul	930	0	8,527	Two-33%
1989	350	2-CL	14-Aug	1,550	4	3,480	Three
1990	884	1-FB	10-Jul	2,050	2	4,150	Two-33%
1991	5,735	1-CL	24-Jul	1,590	0	14,180	Two-33%
1992	4,887	1-FB	21-Jul	6,615	1	12,764	Two-33%
1993	2,895	1-CL	19-Jul	90	0	9,048	Two-33%
1994	5,144	1-CL	21-Jul	53,890	10	13,202	Two-33%
1995	9,025	1-CL	22-Jul	50	0	39,867	Tower
1996	20,710	1-CL	8-Jul	40,100	2	12,655	Tower
1997	5,967	1-FB	16-Jul	-	-	14,302	Tower
1998	No survey	-	-	-	-	13,808	Tower
1999	1,741	2-FB	23-Jul	-	-	4,218	Tower
2000	3,383	2-FB	20-Jul	?	-	10,604	Tower
Avg	-	-	-	-	-	**11,225**	-
Min	-	-	-	-	-	**2,154**	-
Max	-	-	-	-	-	**39,867**	-

[a] Method two used the aerial survey count of chum salmon and expanded it as: $48.059*(\text{Survey Count})^{0.657142}$. Method two was only used when surveys were rated as a 1 or 2 and when the survey date was after July 7th. Method two was not used if the pink to chum ratio exceeded 100 and the chum count seemed overly high or overly low. Methodology two has an associated average absolute percent error of 33%. Method three was based upon the regression of total escapement of the Flambeau and the Eldorado chum salmon runs (n = 22, correlation = 0.704, significant at the 0.005 level, regression: Eldorado Total = Flambeau total/0.661) and has an associated 60% average absolute percent error. An updated estimate of the 2000 Eldorado River chum escapement is 11,617 an increase of 1,013 (9.6%) fish from the estimate used in this report (Tom Kohler, personal communication 11/30/00).

Table 8. Estimates of total escapement of chum salmon in the Penny River of Norton Sound from 1974-2000.

Year	Survey Count of Chum Salmon	Survey Rating & Observer	Date of Survey	Count of Pink Salmon During Survey	Pink to Chum Salmon Ratio	Chum Salmon Total Escapement Estimate	Escapement Estimate Methodology & Average Error[a]
1974	No survey	-	-	-	-	407	Four-10%
1975	249	1-PC	19-Jul	335	1	1,805	Two-33%
1976	No survey	-	-	-	-	305	Four-10%
1977	No survey	-	-	-	-	780	Four-10%
1978	No survey	-	-	-	-	1,589	Four-10%
1979	No survey	-	-	-	-	213	Four-10%
1980	No survey	-	-	-	-	1,576	Four-10%
1981	No survey	-	-	-	-	1,500	Four-10%
1982	8	2-LS	1-Jul	350	44	584	Four-10%
1983	No survey	-	-	-	-	470	Four-10%
1984	No survey	-	-	-	-	812	Four-10%
1985	90	1-CL	13-Jul	-	-	925	Two-33%
1986	6	3-CL	10-Jul	-	-	607	Four-10%
1987	60	1-CL	14-Jul	-	-	708	Two-33%
1988	No survey	-	-	-	-	515	Four-10%
1989	No survey	-	-	-	-	218	Four-10%
1990	No survey	-	-	-	-	266	Four-10%
1991	No survey	-	-	-	-	1,041	Four-10%
1992	No survey	-	-	-	-	638	Four-10%
1993	No survey	-	-	-	-	626	Four-10%
1994	No survey	-	-	-	-	786	Four-10%
1995	15	4-FB	11-Jul	-	-	1,594	Four-10%
1996	No survey	-	-	-	-	878	Four-10%
1997	No survey	-	-	-	-	904	Four-10%
1998	43	2-TK	21-Jul	10,490	244	569	Two-33%
1999	15	5-CL	12-Jul	-	-	285	Two-33%
2000	0	1-TK	21-Jul	?	-	600	Four-10%
Avg	-	-	-	-	-	**785**	-
Min	-	-	-	-	-	**213**	-
Max	-	-	-	-	-	**1,805**	-

[a] Method two used the aerial survey count of chum salmon and expanded it as: $48.059*(\text{Survey Count})^{0.657142}$. Method two was only used when surveys were rated as a 1 or 2 and when the survey date was after July 7th. Method two was not used if the pink to chum ratio exceeded 100 and the chum count seemed overly high or overly low. Methodology two has an associated average absolute percent error of 33%. Method four assumed the average proportion of the Penny River escapement to the sum of the total escapements into the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, and Eldorado rivers for the years 1985, 1987, 1998, and 1999 was a constant value (0.018). And, that this value could be applied to the other years in the data set. The method four procedure for the Penny River chum salmon population has an associated average absolute percent error of 10%.

Table 9. Estimates of total escapement of chum salmon in the Cripple River of Norton Sound from 1974-2000.

Year	Survey Count of Chum Salmon	Survey Rating & Observer	Date of Survey	Count of Pink Salmon During Survey	Pink to Chum Salmon Ratio	Chum Salmon Total Escapement Estimate	Escapement Estimate Methodology & Average Error [a]
1974	No survey	-	-	-	-	494	Four-19%
1975	No survey	-	-	-	-	650	Four-19%
1976	No survey	-	-	-	-	370	Four-19%
1977	No survey	-	-	-	-	948	Four-19%
1978	No survey	-	-	-	-	1,929	Four-19%
1979	No survey	-	-	-	-	259	Four-19%
1980	No survey	-	-	-	-	1,914	Four-19%
1981	No survey	-	-	-	-	1,821	Four-19%
1982	No survey	-	-	-	-	709	Four-19%
1983	25	1-LS	12-Jul	600	24	398	Two-33%
1984	No survey	-	-	-	-	986	Four-19%
1985	180	1-CL	13-Jul	730	4	1,458	Two-33%
1986	130	1-SM	01-Jul	0	-	737	Four-19%
1987	68	1-CL	14-Jul	-	-	769	Two-33%
1988	No survey	-	-	-	-	625	Four-19%
1989	No survey	-	-	-	-	265	Four-19%
1990	No survey	-	-	-	-	323	Four-19%
1991	2,090	1-CL	21-Jul	470	0	7,304	Two-33%
1992	No survey	-	-	-	-	775	Four-19%
1993	No survey	-	-	-	-	760	Four-19%
1994	No survey	-	-	-	-	954	Four-19%
1995	No survey	-	-	-	-	1,935	Four-19%
1996	No survey	-	-	-	-	1,066	Four-19%
1997	105	1-CL	11-Jul	600	6	1,023	Two-33%
1998	No survey	-	-	-	-	845	Four-19%
1999	200	5-CL	12-Jul	-	-	1,563	Two-33%
2000	-	1-TK	21-Jul	?	-	729	Four-19%
Avg	-	-	-	-	-	**1,171**	-
Min	-	-	-	-	-	**259**	-
Max	-	-	-	-	-	**7,304**	-

[a] Method two used the aerial survey count of chum salmon and expanded it as: $48.059*(\text{Survey Count})^{0.657142}$. Method two was only used when surveys were rated as a 1 or 2 and when the survey date was after July 7th. Method two was not used if the pink to chum ratio exceeded 100 and the chum count seemed overly high or overly low. Methodology two has an associated average absolute percent error of 33%. Method four assumed the average proportion of the Cripple River escapement to the sum of the total escapements into the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, and Eldorado rivers for the years 1983, 1985, 1987, and 1997 was a constant value (0.022). And, that this value could be applied to the other years in the data set. The method four procedure for the Cripple River chum salmon population has an associated average absolute percent error of 19%.

Table 10. Estimated average percent absolute error associated with expansions of chum salmon surveys for streams of Subdistrict One of Norton Sound (average percent error associated with methodology two).

Year	Subdistrict One of Norton Sound Stream	Total Enumeration of Chum Salmon	Predicted Total escapement of Chum Salmon	Residual (Observed Minus Predicted)	Absolute Error	Percent Absolute Error
1997	Eldorado	14,302	14,554	(252)	252	2%
1999	Eldorado	4,218	6,478	(2,260)	2,260	54%
2000	Eldorado	10,604	10,024	580	580	5%
1994	Nome	2,893	2,236	657	657	23%
1994	Nome	2,893	2,257	636	636	22%
1995	Nome	5,092	2,387	2,705	2,705	53%
1995	Nome	5,092	6,778	(1,686)	1,686	33%
1997	Nome	5,131	4,369	762	762	15%
1998	Nome	976	2,193	(1,217)	1,217	125%
1999	Nome	1,048	2,362	(1,314)	1,314	125%
2000	Nome	4,051	3,418	633	633	16%
1996	Snake	2,772	2,485	287	287	10%
1996	Snake	2,772	2,341	431	431	16%
1998	Snake	11,067	7,228	3,839	3,839	35%
Average					**1,233**	**33%**

Table 11. Estimated average percent absolute error associated with estimates of the Sinuk River total escapement in years when those estimates were based upon method three (regression comparisons between significantly related escapement data sets).

Year	Estimated Total Chum Escapement in Sinuk River	Estimated Total Chum Escapement in Bonanza River	Expected Total Chum Escapement in Sinuk River [a]	Residual (Observed Minus Predicted)	Absolute Error	Percent Absolute Error
1974	2,713	3,950	5,830	(3,117)	3,117	115%
1975	12,375	1,141	1,685	10,690	10,690	86%
1977	13,308	4,470	6,599	6,709	6,709	50%
1978	18,725	14,581	21,524	(2,799)	2,799	15%
1980	7,147	3,718	5,489	1,659	1,659	23%
1981	13,925	6,775	10,001	3,924	3,924	28%
1983	7,441	3,636	5,367	2,074	2,074	28%
1985	6,885	3,806	5,618	1,267	1,267	18%
1986	7,003	3,072	4,535	2,467	2,467	35%
1987	12,161	1,511	2,230	9,931	9,931	82%
1988	7,258	2,441	3,604	3,655	3,655	50%
1991	13,663	5,925	8,746	4,917	4,917	36%
1993	6,052	3,007	4,439	1,613	1,613	27%
1994	4,905	5,178	7,644	(2,740)	2,740	56%
1995	9,464	11,182	16,507	(7,042)	7,042	74%
1996	6,658	7,049	10,406	(3,748)	3,748	56%
1997	9,212	4,140	6,112	3,100	3,100	34%
1999	6,370	2,304	3,401	2,969	2,969	47%
Average	**9,181**	**4,883**			**4,134**	**48%**

[a] Correlation between Sinuk and Bonanza total estimates of chum salmon escapement = 0.487, n = 18, significant at the 0.025 level. Regression was: Sinuk total = 1.476*Bonanza total.

Table 12. Estimated average percent absolute error associated with estimates of the Nome River total escapement in years when those estimates were based upon method three (regression comparisons between significantly related escapement data sets).

Year	Estimated Total Chum Escapement in Nome River	Estimated Total Chum Escapement in Solomon River	Expected Total Chum Escapement in Nome River [a]	Residual (Observed Minus Predicted)	Absolute Error	Percent Absolute Error
1974	4,057	1,350	3,664	393	393	10%
1977	9,356	1,926	5,230	4,126	4,126	44%
1978	13,366	2,842	7,716	5,650	5,650	42%
1980	17,275	8,431	22,890	(5,615)	5,615	33%
1982	3,560	2,805	7,614	(4,054)	4,054	114%
1983	1,552	2,084	5,658	(4,106)	4,106	264%
1985	6,040	2,965	8,049	(2,009)	2,009	33%
1986	4,260	1,377	3,739	521	521	12%
1987	6,243	1,207	3,277	2,967	2,967	48%
1988	4,165	398	1,082	3,083	3,083	74%
1990	3,005	459	1,246	1,759	1,759	59%
1991	10,289	3,981	10,809	(520)	520	5%
1993	5,925	2,525	6,854	(929)	929	16%
1995	5,092	2,106	5,718	(626)	626	12%
1996	3,883	2,141	5,813	(1,930)	1,930	50%
1997	5,131	2,111	5,730	(599)	599	12%
1998	976	925	2,510	(1,534)	1,534	157%
1999	1,048	637	1,728	(680)	680	65%
2000	4,051	1,294	3,512	539	539	13%
Average	**5,751**	**2,188**			**2,192**	**56%**

[a] Correlation between Nome and Solomon total estimates of chum salmon escapement = 0.808, n = 19, significant at the 0.005 level. Regression was: Nome total = 0.368/Solomon total.

Table 13. Estimated average percent absolute error associated with estimates of the Bonanza River total escapement in years when those estimates were based upon method three (regression comparisons between significantly related escapement data sets).

Year	Estimated Total Chum Escapement in Bonanza River	Estimated Total Chum Escapement in Combined Flambeau-Eldorado Rivers	Expected Total Chum Escapement in Bonanza River [a]	Residual (Observed Minus Predicted)	Absolute Error	Percent Absolute Error
1974	3,950	8,936	1,774	2,176	2,176	55%
1975	1,141	3,888	772	370	370	32%
1976	3,496	4,871	967	2,529	2,529	72%
1977	4,470	11,985	2,379	2,092	2,092	47%
1978	14,581	36,932	7,330	7,251	7,251	50%
1979	1,004	4,117	817	187	187	19%
1980	3,718	44,810	8,894	(5,175)	5,175	139%
1981	6,775	50,448	10,013	(3,237)	3,237	48%
1982	2,383	17,875	3,548	(1,165)	1,165	49%
1983	3,636	9,541	1,894	1,742	1,742	48%
1985	3,806	24,444	4,852	(1,046)	1,046	27%
1987	1,511	12,018	2,385	(874)	874	58%
1991	5,925	20,217	4,013	1,913	1,913	32%
1996	7,049	26,268	5,214	1,836	1,836	26%
1997	4,140	23,757	4,715	(575)	575	14%
1999	2,304	4,855	964	1,340	1,340	58%
2000	4,876	14,551	2,888	1,988	1,988	41%
	4,398	**18,795**			**2,088**	**48%**

[a] Correlation between Bonanza and combined Flambeau and Eldorado total estimates of chum salmon escapement = 0.597, n = 17, significant at the 0.01 level. Regression was: Bonanza total = 0.198*Flambeau-Eldorado combined total.

Table 14. Estimated average percent absolute error associated with estimates of the Solomon River total escapement in years when those estimates were based upon method three (regression comparisons between significantly related escapement data sets).

Year	Estimated Total Chum Escapement in Nome River	Estimated Total Chum Escapement in Solomon River	Expected Total Chum Escapement in Solomon River [a]	Residual (Observed Minus Predicted)	Absolute Error	Percent Absolute Error
1974	4,057	1,350	1,494	(145)	145	11%
1977	9,356	1,926	3,446	(1,520)	1,520	79%
1978	13,366	2,842	4,923	(2,081)	2,081	73%
1980	17,275	8,431	6,363	2,068	2,068	25%
1982	3,560	2,805	1,311	1,493	1,493	53%
1983	1,552	2,084	572	1,512	1,512	73%
1985	6,040	2,965	2,225	740	740	25%
1986	4,260	1,377	1,569	(192)	192	14%
1987	6,243	1,207	2,300	(1,093)	1,093	91%
1988	4,165	398	1,534	(1,136)	1,136	285%
1990	3,005	459	1,107	(648)	648	141%
1991	10,289	3,981	3,790	192	192	5%
1993	5,925	2,525	2,182	342	342	14%
1995	5,092	2,106	1,876	231	231	11%
1996	3,883	2,141	1,430	711	711	33%
1997	5,131	2,111	1,890	221	221	10%
1998	976	925	360	565	565	61%
1999	1,048	637	386	251	251	39%
2000	4,051	1,294	1,492	(199)	199	15%
Average	**5,751**	**2,188**			**807**	**56%**

[a] Correlation between Nome and Solomon total estimates of chum salmon escapement = 0.808, n = 19, significant at the 0.005 level. Regression was: Solomon total = 0.368*Nome total.

Table 15. Estimated average percent absolute error associated with estimates of the Flambeau River total escapement in years when those estimates were based upon method three (regression comparisons between significantly related escapement data sets).

Year	Estimated Total Chum Escapement in Flambeau River	Estimated Total Chum Escapement in Eldorado River	Expected Total Chum Escapement in Flambeau River [a]	Residual (Observed Minus Predicted)	Absolute Error	Percent Absolute Error
1974	1,511	7,426	4,909	(3,398)	3,398	225%
1976	2,362	2,509	1,659	703	703	30%
1977	5,279	6,706	4,433	846	846	16%
1978	16,331	20,601	13,620	2,711	2,711	17%
1979	1,963	2,154	1,424	539	539	27%
1980	24,511	20,299	13,420	11,091	11,091	45%
1981	23,073	27,374	18,098	4,976	4,976	22%
1982	13,099	4,776	3,158	9,941	9,941	76%
1983	5,059	4,482	2,963	2,096	2,096	41%
1984	9,564	11,846	7,831	1,733	1,733	18%
1985	9,694	14,750	9,752	(58)	58	1%
1986	9,414	6,065	4,010	5,404	5,404	57%
1987	1,086	10,931	7,227	(6,141)	6,141	565%
1988	3,774	8,527	5,637	(1,864)	1,864	49%
1991	6,037	14,180	9,374	(3,337)	3,337	55%
1992	3,238	12,764	8,439	(5,201)	5,201	161%
1993	6,103	9,048	5,982	121	121	2%
1994	12,889	13,202	8,728	4,162	4,162	32%
1995	16,474	39,867	26,357	(9,883)	9,883	60%
1996	13,613	12,655	8,366	5,247	5,247	39%
1999	637	4,218	2,789	(2,152)	2,152	338%
2000	3,947	10,604	7,010	(3,064)	3,064	78%
Average	**8,621**	**12,045**			**3,849**	**89%**

[a] Correlation between Flambeau and Eldorado total estimates of chum salmon escapement = 0.704, n = 22, significant at the 0.005 level. Regression was: Flambeau total = 0.661*Eldorado total.

Table 16. Estimated average percent absolute error associated with estimates of the Eldorado River total escapement in years when those estimates were based upon method three (regression comparisons between significantly related escapement data sets).

Year	Estimated Total Chum Escapement in Flambeau River	Estimated Total Chum Escapement in Eldorado River	Expected Total Chum Escapement in Eldorado River [a]	Residual (Observed Minus Predicted)	Absolute Error	Percent Absolute Error
1974	1,511	7,426	2,285	5,140	5,140	69%
1976	2,362	2,509	3,573	(1,064)	1,064	42%
1977	5,279	6,706	7,985	(1,279)	1,279	19%
1978	16,331	20,601	24,701	(4,100)	4,100	20%
1979	1,963	2,154	2,969	(815)	815	38%
1980	24,511	20,299	37,075	(16,776)	16,776	83%
1981	23,073	27,374	34,901	(7,526)	7,526	27%
1982	13,099	4,776	19,813	(15,036)	15,036	315%
1983	5,059	4,482	7,652	(3,170)	3,170	71%
1984	9,564	11,846	14,467	(2,621)	2,621	22%
1985	9,694	14,750	14,663	88	88	1%
1986	9,414	6,065	14,240	(8,175)	8,175	135%
1987	1,086	10,931	1,643	9,288	9,288	85%
1988	3,774	8,527	5,708	2,819	2,819	33%
1991	6,037	14,180	9,132	5,048	5,048	36%
1992	3,238	12,764	4,898	7,867	7,867	62%
1993	6,103	9,048	9,231	(183)	183	2%
1994	12,889	13,202	19,496	(6,295)	6,295	48%
1995	16,474	39,867	24,918	14,949	14,949	37%
1996	13,613	12,655	20,591	(7,936)	7,936	63%
1999	637	4,218	963	3,255	3,255	77%
2000	3,947	10,604	5,969	4,635	4,635	44%
Average	**8,621**	**12,045**			**5,821**	**60%**

[a] Correlation between Flambeau and Eldorado total estimates of chum salmon escapement = 0.704, n = 22, significant at the 0.005 level. Regression was: Eldorado total = 0.661/Flambeau total.

Table 17. Estimated average percent absolute error associated with estimates of the Snake River total escapement in years without surveys when those estimates were based upon method four (the small stream methodology).

Year	Sum of Estimated Total Escapements of Chum Salmon in the Sinuk, Nome, Bonanza, Solomon, Flambeau and Eldorado Rivers	Proportion that the Snake River Total Escapement was of the Total Shown in Column Two (Observed Value)	Predicted Snake River Total Escapement of Chum Salmon Using the Constant Proportion of 7.6%	Residual (Observed Minus Expected) Expressed as Absolute Error	Percent Absolute Error
1977	41,045	5.7%	3,136	811	35%
1985	44,139	10.9%	3,373	1,418	30%
1986	31,191	8.1%	2,383	141	6%
1987	33,140	5.7%	2,532	643	34%
1991	54,075	7.0%	4,132	335	9%
1992	31,152	13.9%	2,380	1,949	45%
1993	32,661	6.5%	2,495	380	18%
1994	40,132	8.8%	3,066	453	13%
1995	84,185	5.2%	6,432	2,039	46%
1996	45,999	6.0%	3,515	743	27%
1997	44,025	14.0%	3,364	2,820	46%
1999	15,213	3.2%	1,162	678	140%
2000	31,969	4.4%	2,443	1,043	75%
Average	**42,866**	**7.6%**		**1,035**	**40%**

Table 18. Estimated average percent absolute error associated with estimates of the Penny River total escapement in years without surveys when those estimates were based upon method four (the small stream methodology).

Year	Estimated Total Escapements of Chum Salmon in the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau and Eldorado Rivers	Estimated Total Escapement of Chum Salmon in the Penny River	Proportion that the Penny River Total Escapement was of the Total Shown in Column Two (Observed Value)	Predicted Penny River Total Escapement of Chum Salmon Using the Constant Proportion of 1.8%	Residual (Observed Minus Expected) Expressed as Absolute Error	Percent Absolute Error
1985	48,930	925	0.019	880	44	5%
1987	35,030	708	0.020	630	78	11%
1998	38,685	569	0.015	696	127	22%
1999	15,697	285	0.018	282	2	1%
Average		**622**	**0.018**		**63**	**10%**

Table 19. Estimated average percent absolute error associated with estimates of the Cripple River total escapement in years without surveys when those estimates were based upon method four (the small stream methodology).

Year	Estimated Total Escapements of Chum Salmon in the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau and Eldorado Rivers	Estimated Total Escapement of Chum Salmon in the Cripple River	Proportion that the Cripple River Total Escapement was of the Total Shown in Column Two (Observed Value)	Predicted Cripple River Total Escapement of Chum Salmon Using the Constant Proportion of 2.2%	Residual (Observed Minus Expected) Expressed as Absolute Error	Percent Absolute Error
1983	26,108	398	0.015	570	172	43%
1985	48,930	1,458	0.030	1,069	389	27%
1987	35,030	769	0.022	765	4	1%
1997	50,209	1,023	0.020	1,097	74	7%
Average		**912**	**0.022**		**160**	**19%**

Table 20. Estimated Subdistrict One of Norton Sound annual chum salmon escapements, catches, and exploitation rates, 1974-2000.

Year	Estimated Total Chum Escapement to Subdistrict One Streams	Estimated Commercial Fishery Catches of Chum Salmon	Estimated Subsistence Fishery Catches of Chum Salmon	Estimated Total Catches of Chum Salmon	Estimated Total Runs of Chum Salmon to Subdistrict One of Norton Sound	Estimated Exploitation Rate of Chums in Subdistrict One of Norton Sound
1974	23,511	10,431	183	10,614	34,125	31%
1975	32,185	8,364	2,858	11,222	43,407	26%
1976	17,623	7,620	1,705	9,325	26,948	35%
1977	45,097	15,998	12,192	28,190	73,287	38%
1978	91,798	8,782	4,295	13,077	104,875	12%
1979	12,312	5,391	3,273	8,664	20,976	41%
1980	91,090	13,922	5,983	19,905	110,995	18%
1981	86,684	18,666	8,579	27,245	113,929	24%
1982	33,735	13,447	4,831	18,278	52,013	35%
1983	26,977	11,691	7,091	18,782	45,759	41%
1984	46,908	3,744	4,883	8,627	55,535	16%
1985	51,313	6,219	5,667	11,886	63,199	19%
1986	35,060	8,160	8,085	16,245	51,305	32%
1987	36,507	5,646	8,394	14,040	50,547	28%
1988	29,733	1,628	5,952	7,580	37,313	20%
1989	12,594	492	3,399	3,891	16,485	24%
1990	15,375	0	4,246	4,246	19,621	22%
1991	66,216	0	3,715	3,715	69,931	5%
1992	36,895	881	1,684	2,565	39,460	7%
1993	36,162	132	1,766	1,898	38,060	5%
1994	45,392	66	1,673	1,739	47,131	4%
1995	92,107	122	5,344	5,466	97,573	6%
1996	50,715	3	4,333	4,336	55,051	8%
1997	52,462	0	4,996	4,996	57,458	9%
1998	48,591	0	964	964	49,455	2%
1999	17,544	0	337	337	17,881	2%
2000	34,698	0	651	651	35,349	2%
Average	**43,303**	**5,237**	**4,336**	**9,573**	**52,877**	**19%**
Minimum	**12,312**	**0**	**183**	**337**	**16,485**	**2%**
Maximum	**92,107**	**18,666**	**12,192**	**28,190**	**113,929**	**41%**

Data sources: Annual escapement values as listed above are the sum of the total chum salmon escapements estimated for the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, Eldorado, Penny and Cripple Rivers as provided in Tables 1-9. Brennan et al (1999) is the source for commercial catches for the years 1974-1998 and for subsistence catches for the years 1974-1979. Bue (personal communication) is the source for the commercial catches for the years 1999 and 2000. Magdanz (personal communication) is the source for subsistence catches for the years 1980-1999. Subsistence catch for the year 2000 was assumed to be equal to the average of the 1998 and 1999 subsistence catch estimates.

Table 21. Estimated Subdistrict One of Norton Sound brood year chum salmon escapements, recruits resulting from those escapements, and estimated recruits per spawner values for brood years 1974-1995.

Brood Year	Estimated Total Chum Escapement to Subistrict One Streams	Estimated Age-4 Recruits from Brood Year	Estimated Age-5 Recruits from Brood Year	Estimated Total Recruits from Brood Year	Estimated Recruits per Spawner
1974	23,511	52,437	10,488	62,925	2.68
1975	32,185	10,488	55,497	65,985	2.05
1976	17,623	55,497	56,964	112,462	6.38
1977	45,097	56,964	26,006	82,971	1.84
1978	91,798	26,006	22,879	48,886	0.53
1979	12,312	22,879	27,767	50,647	4.11
1980	91,090	27,767	31,599	59,367	0.65
1981	86,684	31,599	25,652	57,252	0.66
1982	33,735	25,652	25,274	50,926	1.51
1983	26,977	25,274	18,657	43,930	1.63
1984	46,908	18,657	8,243	26,899	0.57
1985	51,313	8,243	9,810	18,053	0.35
1986	35,060	9,810	34,966	44,776	1.28
1987	36,507	34,966	19,730	54,696	1.50
1988	29,733	19,730	19,030	38,760	1.30
1989	12,594	19,030	23,565	42,595	3.38
1990	15,375	23,565	48,787	72,352	4.71
1991	66,216	48,787	27,526	76,312	1.15
1992	36,895	27,526	28,729	56,255	1.52
1993	36,162	28,729	24,778	53,507	1.48
1994	45,392	24,778	8,941	33,719	0.74
1995	92,107	8,941	17,674	26,615	0.29
Average	**43,876**	**27,606**	**26,026**	**53,631**	**1.83**
Minimum	**12,312**	**8,243**	**8,243**	**18,053**	**0.29**
Maximum	**92,107**	**56,964**	**56,964**	**112,462**	**6.38**

Table 22. Residuals in the spawner-recruit relationship estimated for chum salmon in Subdistrict One of Norton Sound using standard methodology.

Brood Year	Estimated Total Chum Escapement to Subdistrict One	Estimated Total Recruits from Brood Year	Predicted Total Recruits from Brood Year	Residuals (Observed Minus Predicted)
1974	23,511	62,925	59,742	3,183
1975	32,185	65,985	65,350	635
1976	17,623	112,462	52,144	60,318
1977	45,097	82,971	65,574	17,396
1978	91,798	48,886	39,898	8,988
1979	12,312	50,647	41,793	8,854
1980	91,090	59,367	40,322	19,045
1981	86,684	57,252	43,002	14,250
1982	33,735	50,926	65,806	(14,880)
1983	26,977	43,930	62,672	(18,742)
1984	46,908	26,899	65,087	(38,188)
1985	51,313	18,053	63,534	(45,481)
1986	35,060	44,776	66,087	(21,311)
1987	36,507	54,696	66,288	(11,592)
1988	29,733	38,760	64,324	(25,564)
1989	12,594	42,595	42,441	155
1990	15,375	72,352	48,216	24,136
1991	66,216	76,312	55,767	20,546
1992	36,895	56,255	66,323	(10,069)
1993	36,162	53,507	66,250	(12,743)
1994	45,392	33,719	65,502	(31,784)
1995	92,107	26,615	39,713	(13,098)

Table 23. Stock-recruitment relationship statistics for the chum salmon population that returns to Subdistrict One of Norton Sound based upon the auto-regressive model.

Stock-Recruit Relationship Statistic	District One of Norton Sound Chum Salmon Brood Years 1974-1995
Ricker Alpha	4.4187197
Ricker Beta	0.0000257
Auto-Regressive Parameter ϕ_1	0.601
Significance of Relationship	0.0001
Number of Brood Years	22
MSY Escapement Level	22,976
Estimated Maximum Yield	33,200
Est. MSY Exploitation Rate	59.1%

Table 24. Residuals in the spawner-recruit relationship estimated for chum salmon in Subdistrict One of Norton Sound using auto-regressive methodology.

Brood Year	Estimated Total Chum Escapement to Subdistrict One Streams	Estimated Total Recruits from Brood Year	Predicted Total Recruits from Brood Year	Residuals (Observed Minus Predicted)	Percent Absolute Error
1974	23,511	62,925			
1975	32,185	65,985	64,093	1,892	3%
1976	17,623	112,462	49,734	62,728	56%
1977	45,097	82,971	99,154	(16,183)	20%
1978	91,798	48,886	43,949	4,937	10%
1979	12,312	50,647	44,546	6,101	12%
1980	91,090	59,367	43,383	15,984	27%
1981	86,684	57,252	51,672	5,580	10%
1982	33,735	50,926	73,961	(23,035)	45%
1983	26,977	43,930	50,996	(7,066)	16%
1984	46,908	26,899	50,053	(23,154)	86%
1985	51,313	18,053	35,530	(17,477)	97%
1986	35,060	44,776	29,435	15,341	34%
1987	36,507	54,696	49,849	4,847	9%
1988	29,733	38,760	54,404	(15,644)	40%
1989	12,594	42,595	29,666	12,929	30%
1990	15,375	72,352	45,877	26,475	37%
1991	66,216	76,312	67,995	8,317	11%
1992	36,895	56,255	75,930	(19,838)	35%
1993	36,162	53,507	56,915	(7,817)	16%
1994	45,392	33,719	52,041	(22,569)	77%
1995	92,107	26,615	23,497	3,118	12%
Average					**32%**

Table 25 Bootstrap estimates of the precision associated with the maximum sustained yield escapement level estimated for the chum salmon population that returns to Subdistrict One of Norton Sound (n = 1,000).

Statistic	Subdistrict One of Norton Sound Chum Salmon Brood Years 1974-1995
Mean	23,655
Standard Deviation	1,859
Coefficient of Variation	7.9%
Lower 90% C. I.	20,905
Upper 90% C. I.	26,893
Indicated Bias	678
Indicated % Bias	2.9%

Table 26. Years when annual Subdistrict One of Norton Sound chum salmon escapements were below, within, or above the biological escapement goal range recommended in this report.

Recommended Biological Escapement Goal Range	Years When Escapement Was Below Recommended Level	Years When Escapement Was Within Recommended Level	Years When Escapement Was Above Recommended Level
23,000 to 35,000 Total Spawners in the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, Eldorado, Penny, and Cripple Rivers of Norton Sound	1976, 1979, 1989, 1990, and 1999 5 of the 27 years since 1974 19% 2 Years since 1990 18%	**1974, 1975, 1982, 1983, 1988, and 2000** **6 of the 27 years since 1974** **22%** **1 Year since 1990** **9%**	1977, 1978, 1980, 1981, 1984, 1985, 1986, 1987, 1991, 1992, 1993, 1994, 1995, 1996, 1997, and 1998 16 of the 27 years since 1974 59% 8 Years since 1990 73%

Table 27. Estimated escapement targets for the chum salmon runs in the nine streams that are tributary to Subdistrict One of Norton Sound. Escapement targets are listed as total escapements; aerial surveys of escapements need to be expanded by EQ 2 to relate to these escapement target ranges.

Subdistrict 1 Stream	1974-2000 Average Estimated Escapement	Percent Contribution to Subdistrict One Total	Point Target Total Escapement	Lower Range of Total Target Escapement	Upper Range of Total Target Escapement
Sinuk	7,556	17%	5,100	4,000	6,200
Nome	5,319	12%	3,600	2,900	4,300
Bonanza	4,227	10%	2,800	2,300	3,400
Snake	3,060	7%	2,000	1,600	2,500
Solomon	2,008	5%	1,400	1,100	1,600
Flambeau	7,956	18%	5,200	4,100	6,300
Eldorado	11,225	26%	7,600	6,000	9,200
Penny	785	2%			
Cripple	1,171	3%			
District 1 Total	**43,307**	**100%**	**29,000**	**23,000**	**35,000**

Table 28. Years since 1990 when annual individual streams of Subdistrict One of Norton Sound chum salmon escapements were below, within, or above the recommended escapement target ranges provided in this report. Estimates based upon surveys are only included if they were adequate for method two expansions. Penny and Cripple Rivers are not included because survey data is so sparse for these two small chum salmon producing systems.

Recommended Target Escapement Range	Years When Escapement Was Below Recommended Level	Years When Escapement Was Within Recommended Level	Years When Escapement Was Above Recommended Level
Sinuk River 4,000 to 6,200 Total Estimate of Chum Salmon	0 of the 7 Years 0%	**1993 and 1994 2 of the 7 years 28%**	1991, 1995, 1996, 1997, and 1999 5 of the 7 Years 72%
Nome River 2,900 to 4,300 Total Estimate of Chum Salmon	1994, 1998 and 1999 3 of the 10 Years 30%	**1990, 1996, and 2000 3 of the 10 Years 30%**	1991, 1993, 1995, and 1997 4 of the 10 Years 40%
Bonanza River 2,300 to 3,400 Total Estimate of Chum Salmon	0 of the 6 Years 0%	**1992 and 1999 2 of the 6 Years 33%**	1991, 1996, 1997, and 2000 4 of the 6 Years 67%
Snake River 1,600 to 2,500 Total Estimate of Chum Salmon	1999 and 2000 2 of the 10 Years 20%	**1993 1 of the 10 Years 10%**	1991, 1992, 1994, 1995,1996, 1997, and 1998 7 of the 10 Years 70%
Solomon River 1,100 to 1,600 Total Estimate of Chum Salmon Salmon	1990, 1998, and 1999 3 of the 9 Years 33%	**2000 1 of the 9 Years 11%**	1991, 1993, 1995, 1996, and 1997 5 of the 9 Years 56%
Flambeau River 4,100 to 6,300 Total Estimate of Chum Salmon	1992 and 1999 2 of the 8 Years 25%	**1991, 1993, and 2000 3 of the 8 Years 38%**	1994, 1995, and 1996 3 of the 8 Years 37%
Eldorado River 6,000 to 9,200 Total Estimate Of Chum Salmon	1990 and 1999 2 of the 11 Years 18%	**1993 1 of the 11 Years 9%**	1991, 1992, 1994, 1995, 1996, 1997, 1998, and 2000 8 of the 11 Years 73%

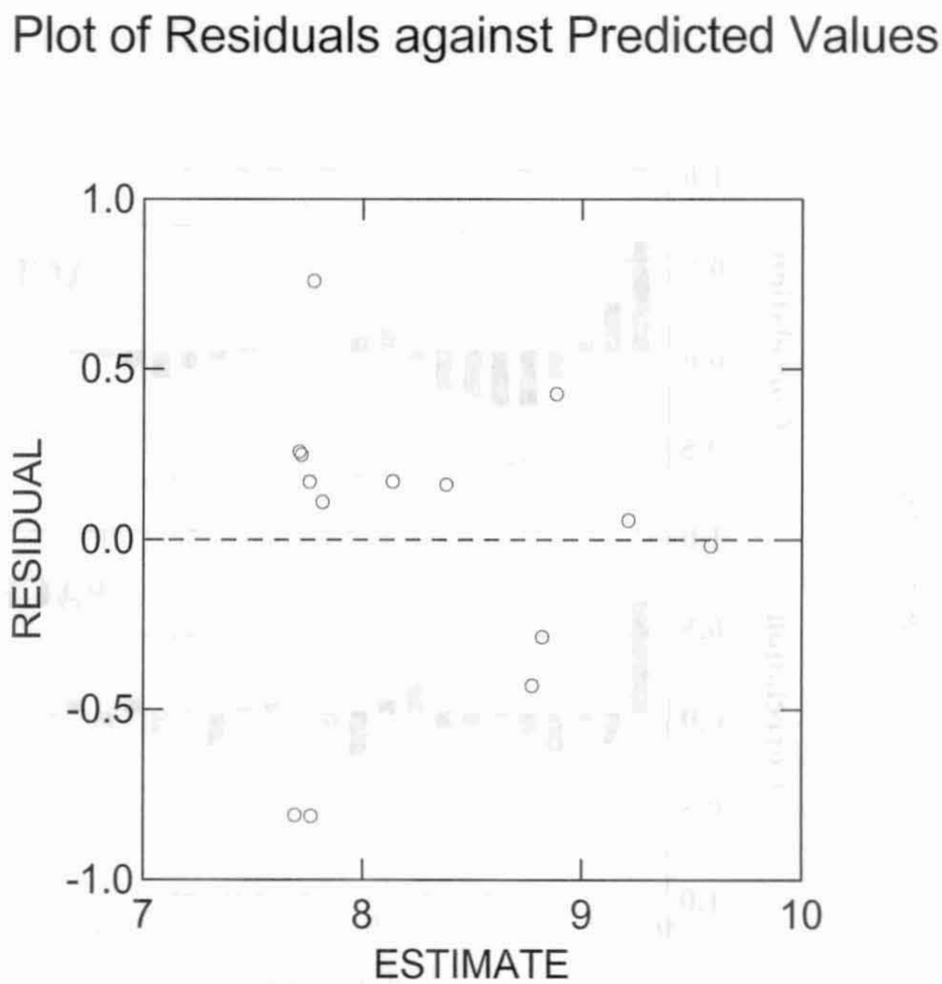

Figure 1. Plot of residuals associated with the survey expansion equation used for method two total escapement estimates for Nome Subdistrict chum salmon spawning populations.

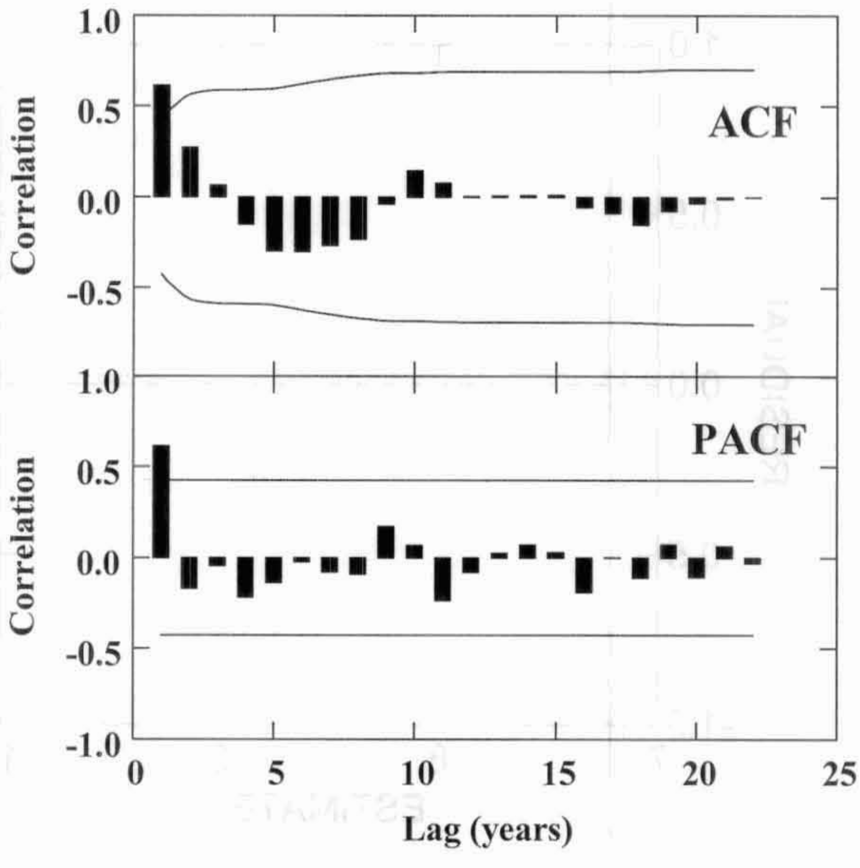

Figure 2. Auto-correlations (ACF) and partial auto-correlations (PACF) among residuals from fit of auto-regressive form of Ricker's model to 1974-1995 Nome Subdistrict chum salmon data.

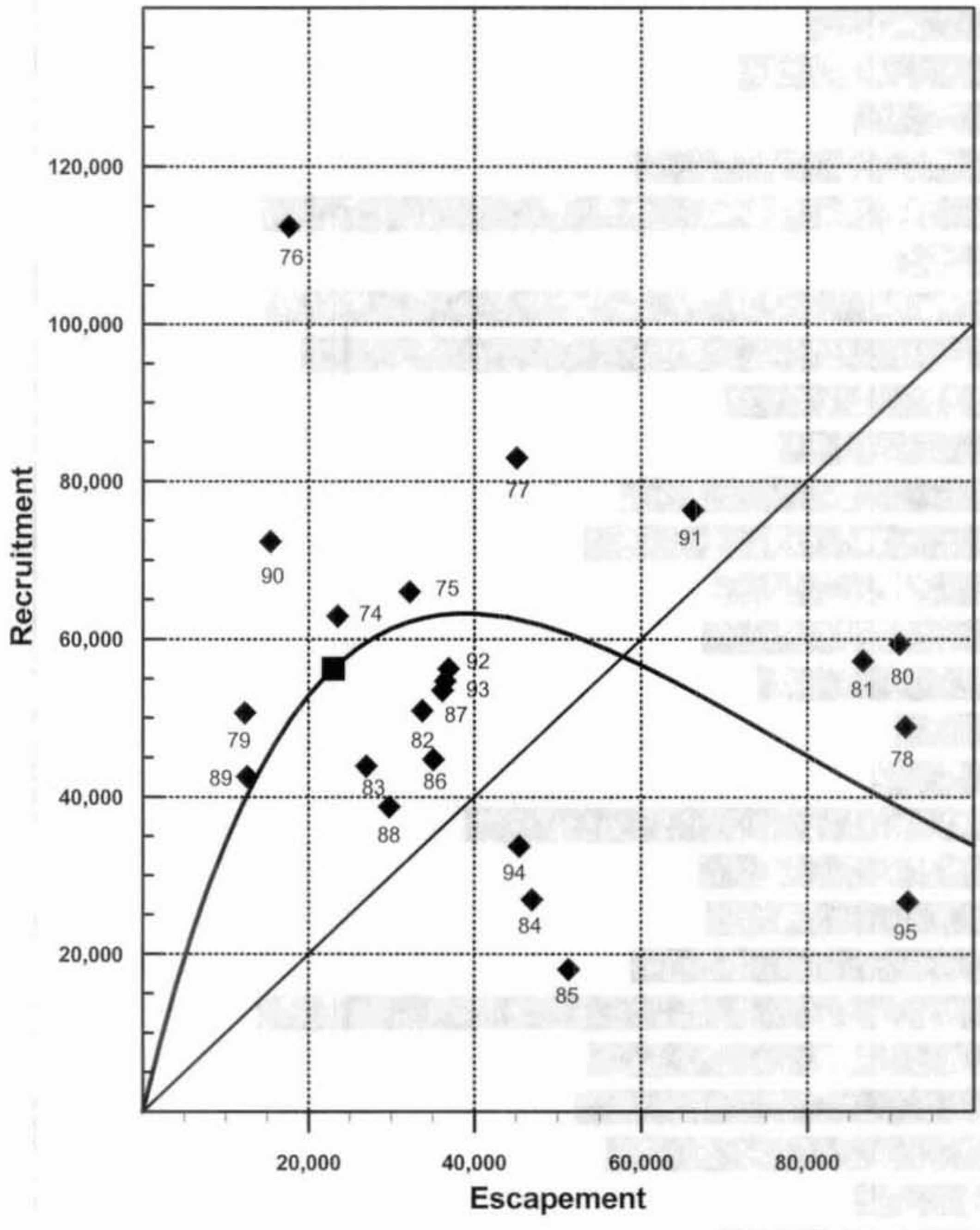

Figure 3. Spawner-recruit relationship for Nome Subdistrict chum salmon, brood years 1974-1995. Note: the diamonds represent individual years, the square is the maximum sustained yield escapement estimate of 22,976.

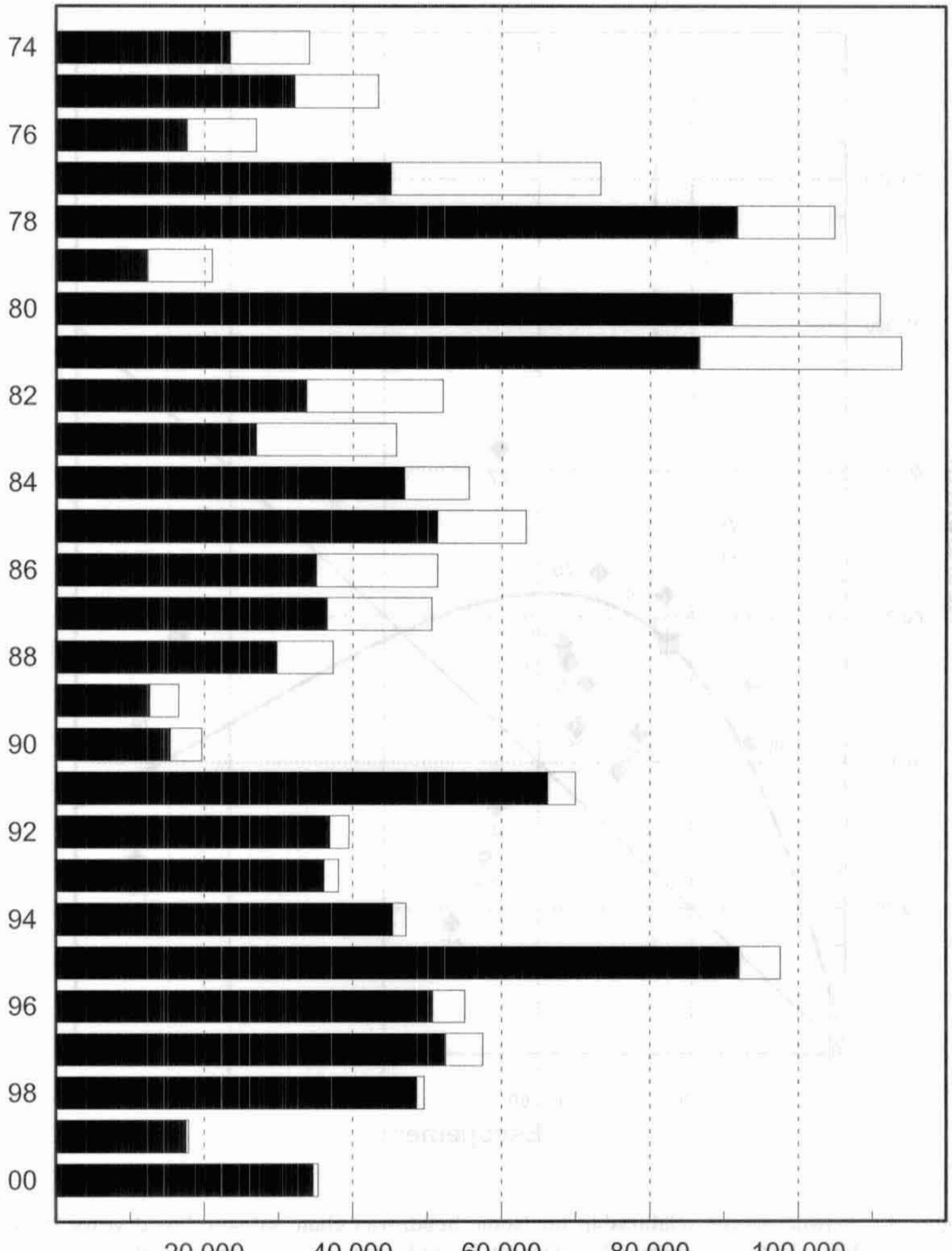

Figure 4. Plot of Nome Subdistrict chum salmon escapements (solid columns) and catches (empty columns) from1974-2000.

APPENDIX A

A MARKOVIAN APPROACH

The information included in this appendix was prepared by Gene Sandone (Regional Supervisor, Arctic-Yukon-Kuskokwim Region (AYK), Division of Commercial Fisheries, Alaska Department of Fish and Game) with help from the AYK Regional staff of the Commercial Fisheries Division of the Alaska Department of Fish and Game. This material was presented by Alaska Department of Fish and Game staff during a public meeting in Nome, Alaska, on February 7, 2001. The attached analysis is basically a Markovian approach to identification of appropriate spawning stock size (Hilborn and Walters 1992; Chapter 7).

Total escapements as presented in this analysis (Tables A-1, A-3, A-4, and A-5) are the same as those given in the main text of this report. Background concerning development of data used to generate Table A-2 is provided in Appendix B. To develop the data as presented in Tables A-3, A-4, and A-5, the subsistence and commercial catch data for Subdistrict One of Norton Sound was allocated among the chum salmon runs returning to the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, Eldorado, Penny and Cripple rivers. The subsistence catch allocations used by Gene Sandone in this analysis were provided in an EXCEL spreadsheet by James Magdanz of the Subsistence Division of the Alaska Department of Fish and Game on January 31, 2001, via e-mail. Commercial catch allocations were based upon documented inshore freshwater abundance of the nine component stocks. The chum salmon returning to the Flambeau and Eldorado Rivers were combined into a "Flambeau-Eldorado" stock as presented in Table A-5.

Escapement, Return, and Yield Data for the Nome Subdistrict Chum Salmon Stock of Norton Sound

This document presents information concerning the average return and yield, in number of fish as well as in aerial survey counts, from chum salmon escapements. This analysis is not based on the Ricker spawner-recruit data, but simply presents in graphs and tabular form, the average return and yield from a specific escapement range for the entire Nome Subdistrict chum salmon stock. This paper presents material that was presented to participants at the meeting in Nome on February 7, 2001 and includes additional graphs and tables specific to individual streams within the Nome Subdistrict of Norton Sound.

In order to understand the graphs and tables a few terms must be defined. They are brood year escapement, return, and yield.

Brood year escapement is the total number of fish estimated to escape and spawn or is the aerial survey count or index of chum salmon that spawned in a particular year.

The return consists of the progeny, or the fish that were produced from an annual spawning event. Please note that those returning fish come back to the stream that they were spawned in typically four or five years after the spawning event. For example, the progeny of the fish that spawned in 1992 primarily returned as 4-year-old fish in 1996 and as 5-year-old fish in 1997. Additionally, a few fish may have returned as 3-year-old in 1995 and as 6-year-old fish in 1998.

Yield is what can be harvested from the return after satisfying escapement needs. For example, if the return from a brood year is 50,000 fish and if we determine that the spawning escapement need is 30,000 fish, then yield would equal 20,000 fish. In other words, 20,000 fish would be available for harvest. If we determine that 50,000 fish are necessary to satisfy the escapement, then the yield is 0. At a yield of 0, there can be no harvest.

Please note that 1996 to 2000 escapements can not be used in this summary because the fish produced from those annual spawning events, or brood year escapements, have not returned yet. . The returns from these escapements will be coming back in 2000 to 2005. Note that the 4-year old component of the 1996 brood year escapement returned during 2000. The 5-year old component of the 1996 brood year escapement will return in 2001.

The following narrative provides a more complete description of the data presented in the following tables and figures.

Table A-1. Nome Subdistrict chum salmon escapement, return, and yield in number of fish, 1974 to 1995.

This data has been converted to total estimated numbers of fish that spawned (it is not in aerial survey count form). The data in the first four columns are ordered from the year with the smallest escapement to the year with the largest escapement. The last five columns are a summary of the yearly data.

Column Heading	What is Contained Within Each Column
Year	The year of the given escapement in the Nome Subdistrict or the brood year.
Escapement	The estimated total number of chum salmon that spawned in rivers of the Nome Subdistrict for the given brood year. Escapements are listed from lowest to highest in the table.
Return	The estimated total return of chum salmon to the Nome Subdistrict that was produced by that brood year escapement. These are the chum salmon that primarily returned four and five years after the spawning event.
Yield	The number of chum salmon that returned above the number that escaped to produce the return (Return - Escapement). This can also be viewed as the number of chum salmon above what is needed to replace the spawning escapement that produced the return.
Escapement Range	The range of escapements.
Average Escapement	The average escapement for years within the escapement range.
Average Return	The average return for years within the escapement range.
Average Yield	The average yield for years that had escapements within the escapement range (Return – Escapement).
Number of Observations	The numbers of years that had escapements that fell within the escapement range.

Figure A-1. Average Return to the Nome Subdistrict for an Escapement Range.

This figure is a graphical representation of the Escapement Range and the Average Return columns from Table A-1. This figure shows that, on average, chum salmon returns to the Nome Subdistrict remain relatively constant for escapements over 20 thousand chum salmon. On average, escapements over 20 thousand chum salmon produce a return between 47 and 55 thousand chum salmon.

Figure A-2. Average Yield for the Nome Subdistrict for an Escapement Range.

This figure is a graphical representation of the Escapement Range and the Average Yield columns from Table A-1. Each bar represents the average number of chum salmon that are left over after replacing the chum salmon that escaped (spawned) to produce them. On average, escapements of 20 to 40 thousand chum salmon produce 19 to 22 thousand chum salmon more than escaped.

Bars that go below the zero line show that, on average, escapements in that range do not produce enough chum salmon to replace themselves. On average, escapements over 50 thousand chum salmon produce approximately 32 thousand less chum salmon then escaped (spawned).

Table A-2. Nome Subdistrict chum salmon escapement, return, and yield in aerial survey counts, 1974 to 1995.

The data in the first four columns are ordered from the year with the smallest aerial survey count to the year with the largest aerial survey count. The last five columns are a summary of the yearly data.

Column Heading	What is Contained Within Each Column
Year	The year of the given aerial survey count in the Nome Subdistrict or the brood year.
Escapement	The number of chum salmon that were counted during an aerial survey in the Nome Subdistrict for the given brood year. Aerial survey counts are listed from lowest to highest in the table.
Return	The estimated total return of chum salmon to the Nome Subdistrict that was produced by that brood year escapement as determined by aerial survey counts. These are the chum salmon that primarily returned four and five years after the spawning event.
Yield	The number of chum salmon that returned above the number that escaped to produce the return (Return - Escapement). This can also be viewed as the number of chum salmon above what is needed to replace the spawning escapement that produced the return.
Escapement Range	The range of aerial survey counts.
Average Escapement	The average aerial survey count for years within the escapement range.
Average Return	The average return for years within the escapement range.
Average Yield	The average yield for years that had aerial survey counts within the escapement range (Return – Escapement).
Number of Observations	The numbers of years that had aerial survey counts that fell within the escapement range.

Figure A-3. Average Return to the Nome Subdistrict for an Escapement Range in aerial survey counts.

This figure is a graphical representation of the Escapement Range and the Average Return columns from Table A-2. This figure shows that, on average, returns remain fairly constant above an aerial survey count of escapement of 5 thousand, with the exception of the 15 to 20 thousand escapement range. The low average return for the 15 to 20 thousand escapement range may be a function of the low number of observations in that grouping.

Figure A-4. Average Yield for the Nome Subdistrict for an Escapement Range in aerial survey counts.

This figure is a graphical representation of the Escapement Range and the Average Yield columns from Table A-2. Each bar represents the average number of chum salmon in aerial survey counts that are left over after replacing the chum salmon that escaped to produce them. On average, aerial survey counts of 5 to 15 thousand chum salmon produce 8 to 9 thousand chum salmon more than escaped.

Bars that go below the zero line show that, on average, aerial survey counts in that range do not produce enough chum salmon to replace themselves. On average, aerial survey counts over 15 thousand chum salmon do not replace themselves.

Tables A-3 to A-5 and Figures A-5 to A-10.

These tables and figures are a further break down for the Snake, Nome and Eldorado-Flambeau Rivers. These tables and figures display data that are in total estimates of chum salmon, not aerial survey counts. Tables A-3, A-4, and A-5 use the same column descriptions as Table A-1 used, but are only for the specific river. Figures A-5, A-7, and A-9 are the same type of figure as Figure A-1 but are only the return for the specific river. Figures A-6, A-8, and A-10 are the same type of figure as Figure A-2 but are only the yield for the specific river.

Table A-1. Nome Subdistrict chum salmon escapement, return, and yield in number of fish, 1974-1995.

Year	Escapement	Return	Yield		Escapement Range	Average Escapement	Average Return	Average Yield	Number of Observations
1979	12,312	50,647	38,335	1	0-10K				0
1989	12,594	42,595	30,001	1	10-20K	14,476	69,514	55,038	4
1990	15,375	72,352	56,977	1	20-30K	26,740	48,538	21,798	3
1976	17,623	112,462	94,839	1	30-40K	35,091	54,358	19,267	6
1974	23,511	62,925	39,414	1	40-50K	45,799	47,863	2,064	3
1983	26,977	43,930	16,953	1	50+K	79,868	47,748	-32,121	6
1988	29,733	38,760	9,027	1					
1975	32,185	65,985	33,800	1					22
1982	33,735	50,926	17,191	1					
1986	35,060	44,776	9,716	1					
1993	36,162	53,507	17,345	1					
1987	36,507	54,696	18,189	1					
1992	36,895	56,255	19,360	1					
1977	45,097	82,971	37,874	1					
1994	45,392	33,719	-11,673	1					
1984	46,908	26,899	-20,009	1					
1985	51,313	18,053	-33,260	1					
1991	66,216	76,312	10,096	1					
1981	86,684	57,252	-29,432	1					
1980	91,090	59,367	-31,723	1					
1978	91,798	48,886	-42,912	1					
1995	92,107	26,615	-65,492	1					

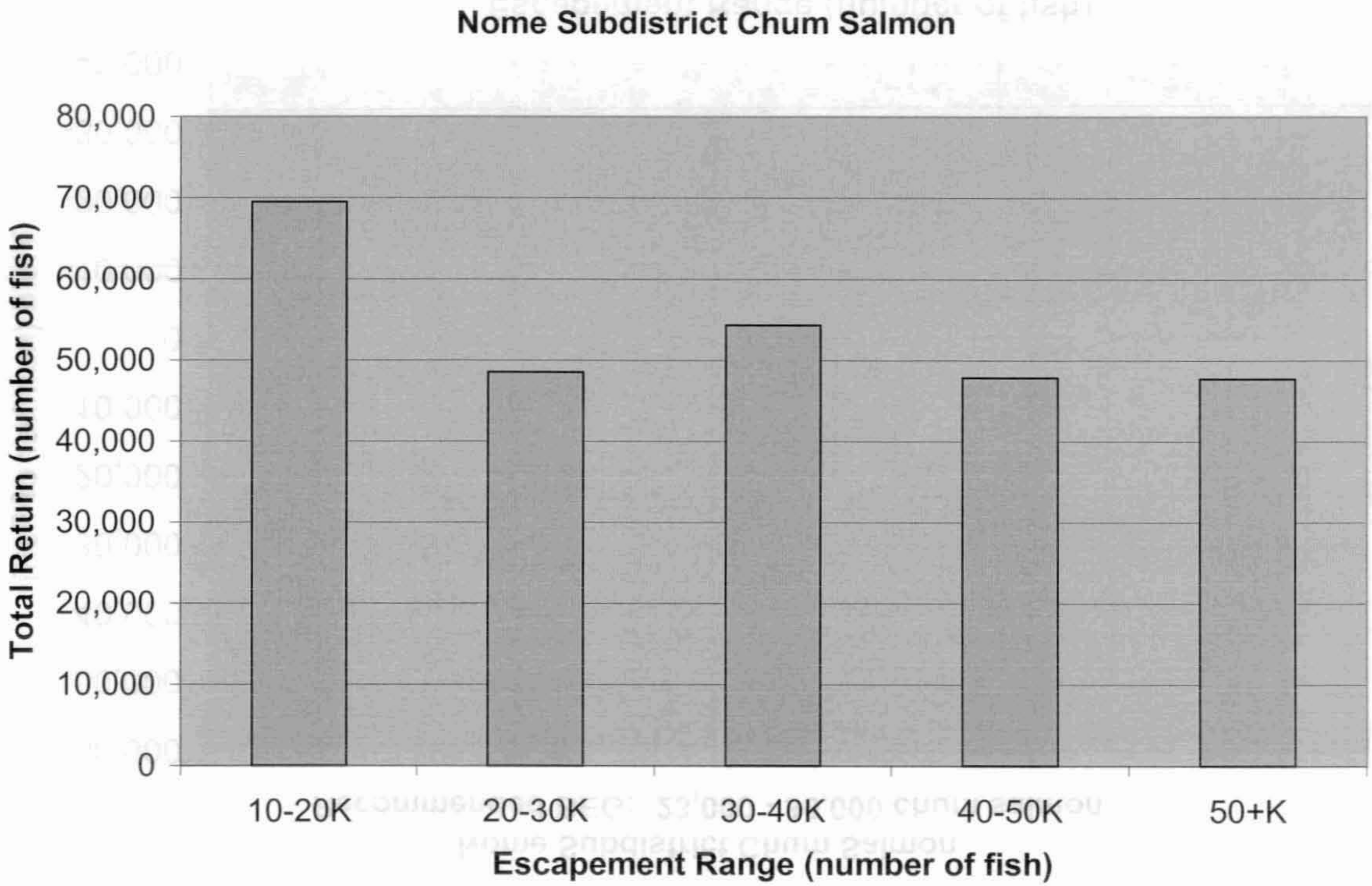

Figure A-1. Average return to the Nome Subdistrict for an escapement range.

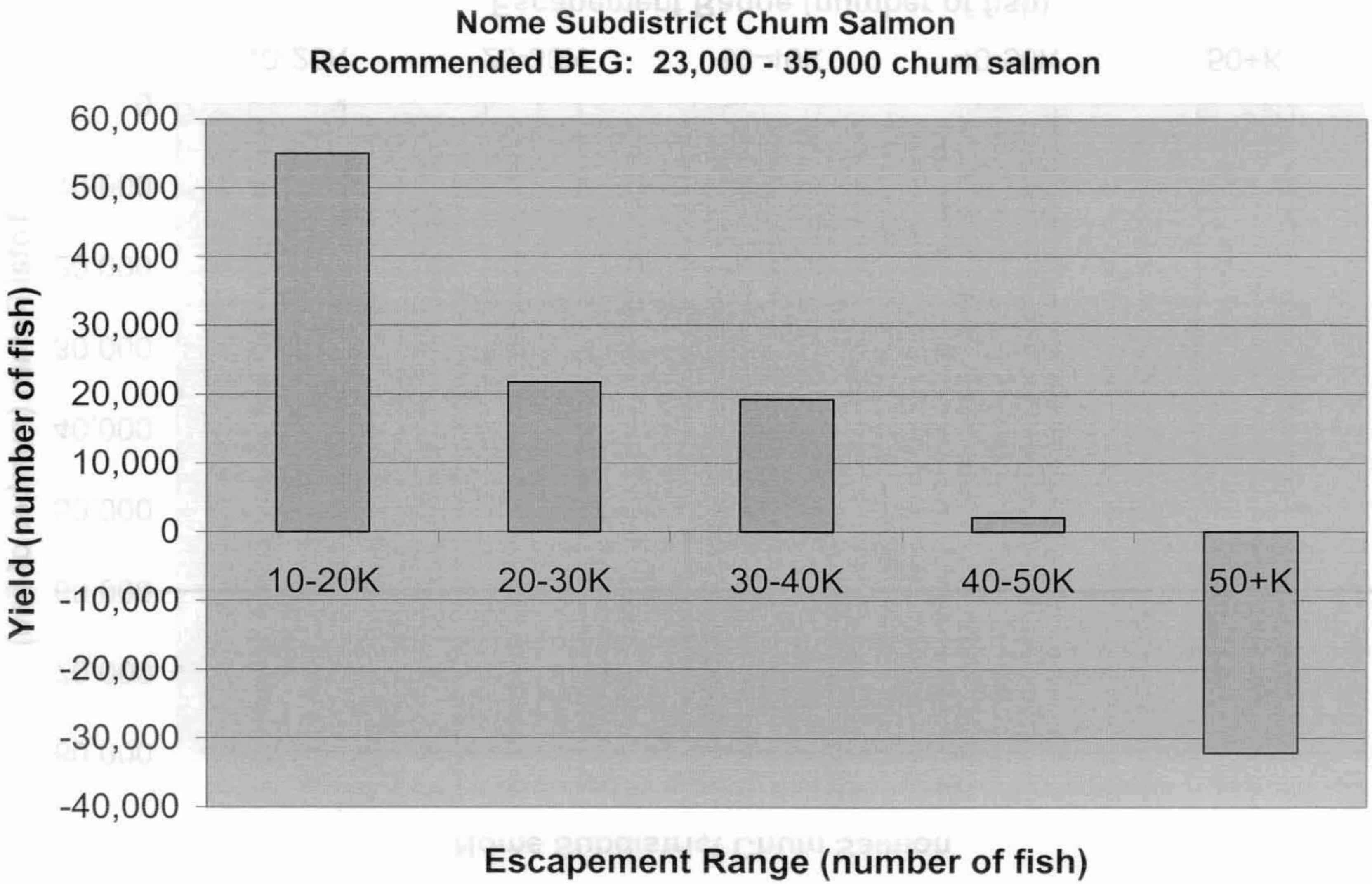

Figure A-2. Average yield for the Nome Subdistrict for an escapement range.

Table A-2. Nome Subdistrict chum salmon escapement, return, and yield in aerial survey counts, 1974-1995.

Year	Escapement	Return	Yield	Escapement Range	Average Escapement	Average Return	Average Yield	Number of Observations
1979	1,611	16,176	14,565	0-5K	2,321	25,624	23,303	4
1989	1,786	12,633	10,846	5-10K	7,995	16,421	8,426	7
1976	2,935	53,030	50,095	10-15K	13,276	21,506	8,230	4
1990	2,950	20,658	17,708	15-20K	15,585	5,751	-9,834	2
1974	5,552	24,548	18,996	20-25K	23,233	18,964	-4,270	2
1983	6,131	13,484	7,353	25+K	40,221	17,876	-22,345	3
1992	8,011	25,004	16,992					
1988	8,126	9,194	1,068					22
1986	9,152	13,211	4,058					
1982	9,309	16,419	7,109					
1993	9,683	13,085	3,402					
1987	10,983	15,496	4,513					
1977	13,588	36,510	22,922					
1975	13,801	27,555	13,754					
1984	14,732	6,462	-8,269					
1994	15,078	8,275	-6,803					
1985	16,092	3,227	-12,865					
1991	21,809	29,903	8,094					
1995	24,658	8,024	-16,633					
1978	39,705	16,338	-23,367					
1981	39,779	18,341	-21,438					
1980	41,180	18,950	-22,230					

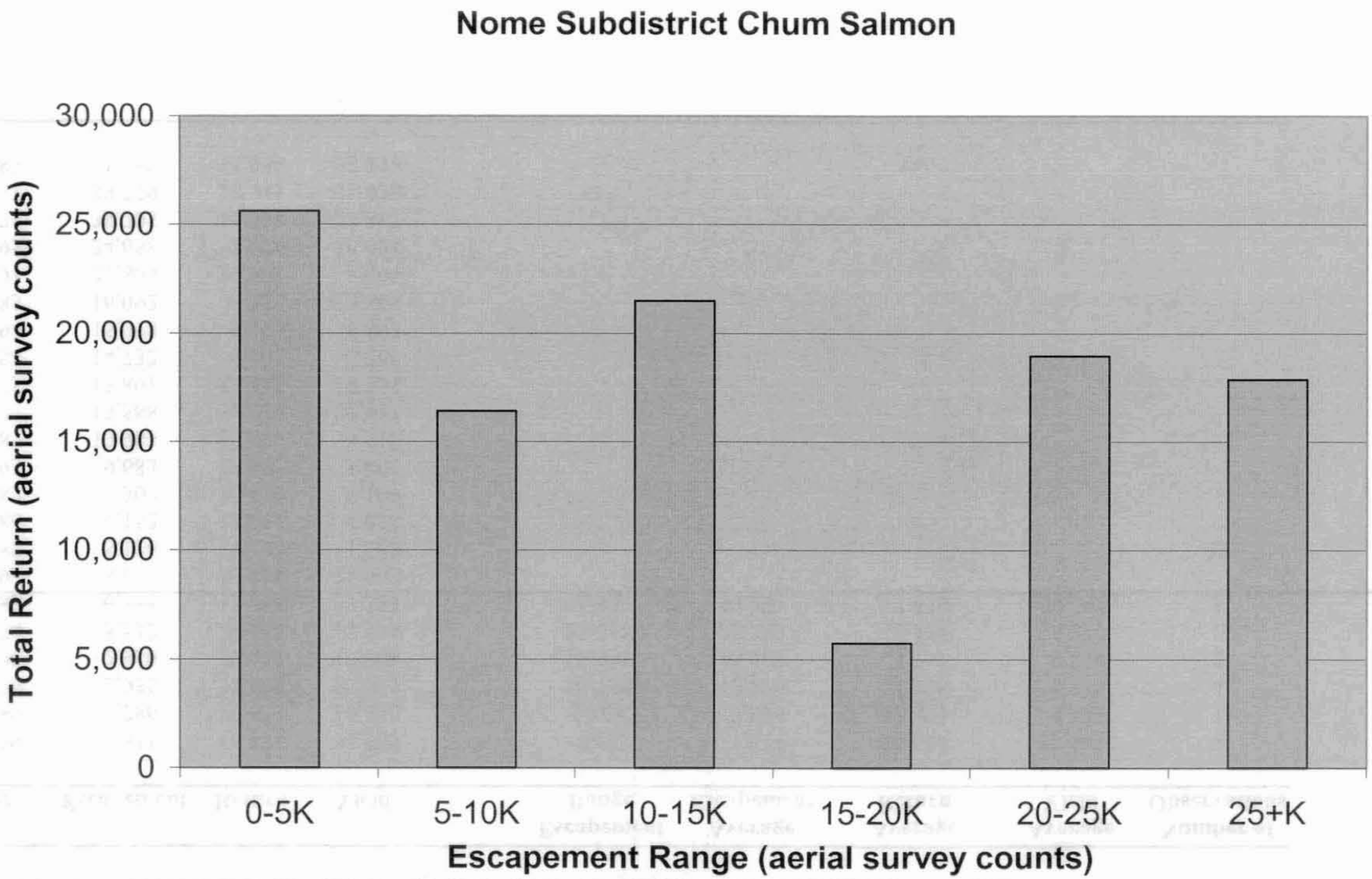

Figure A-3. Average return to the Nome Subdistrict for an escapement range in aerial survey counts.

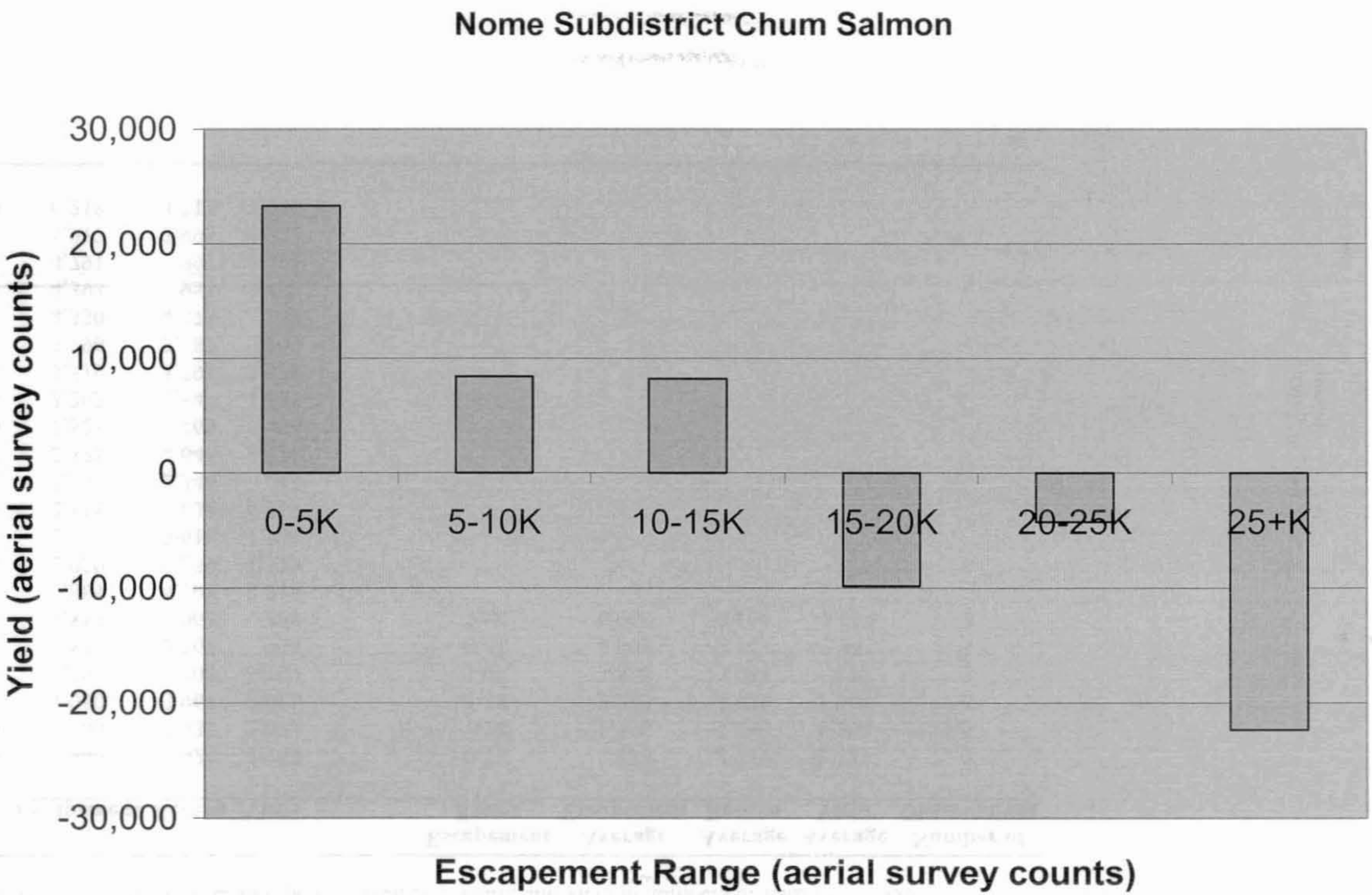

Figure A-4. Average yield for the Nome Subdistrict for an escapement range in aerial survey counts.

Table A-3. Snake River chum salmon escapement, return, and yield in numbers of fish, 1975-1995.

Year	Escapement	Return	Yield	Escapement Range	Average Escapement	Average Return	Average Yield	Number of Observations
1979	840	3,024	2,184	0-1K	850	2,979	2,129	2
1989	860	2,933	2,073	1-2K	1,566	3,860	2,294	5
1990	1,050	3,961	2,911	2-3K	2,235	4,179	1,944	6
1976	1,203	6,402	5,199	3-4K	3,506	3,644	138	3
1978	1,833	2,767	934	4-5k	4,505	2,143	-2,361	3
1983	1,853	2,061	208	>5K	6,068	4,154	-1,914	2
1987	1,889	4,108	2,219					
1988	2,030	3,359	1,329					
1975	2,110	3,618	1,508					
1993	2,115	8,634	6,519					
1982	2,303	2,346	43					
1977	2,325	4,646	2,321					
1986	2,525	2,469	-56					
1984	3,202	1,547	-1,655					
1994	3,519	5,797	2,278					
1991	3,796	3,587	-209					
1992	4,330	4,478	148					
1995	4,393	955	-3,438					
1985	4,791	997	-3,794					
1981	5,917	3,995	-1,922					
1980	6,218	4,312	-1,906					

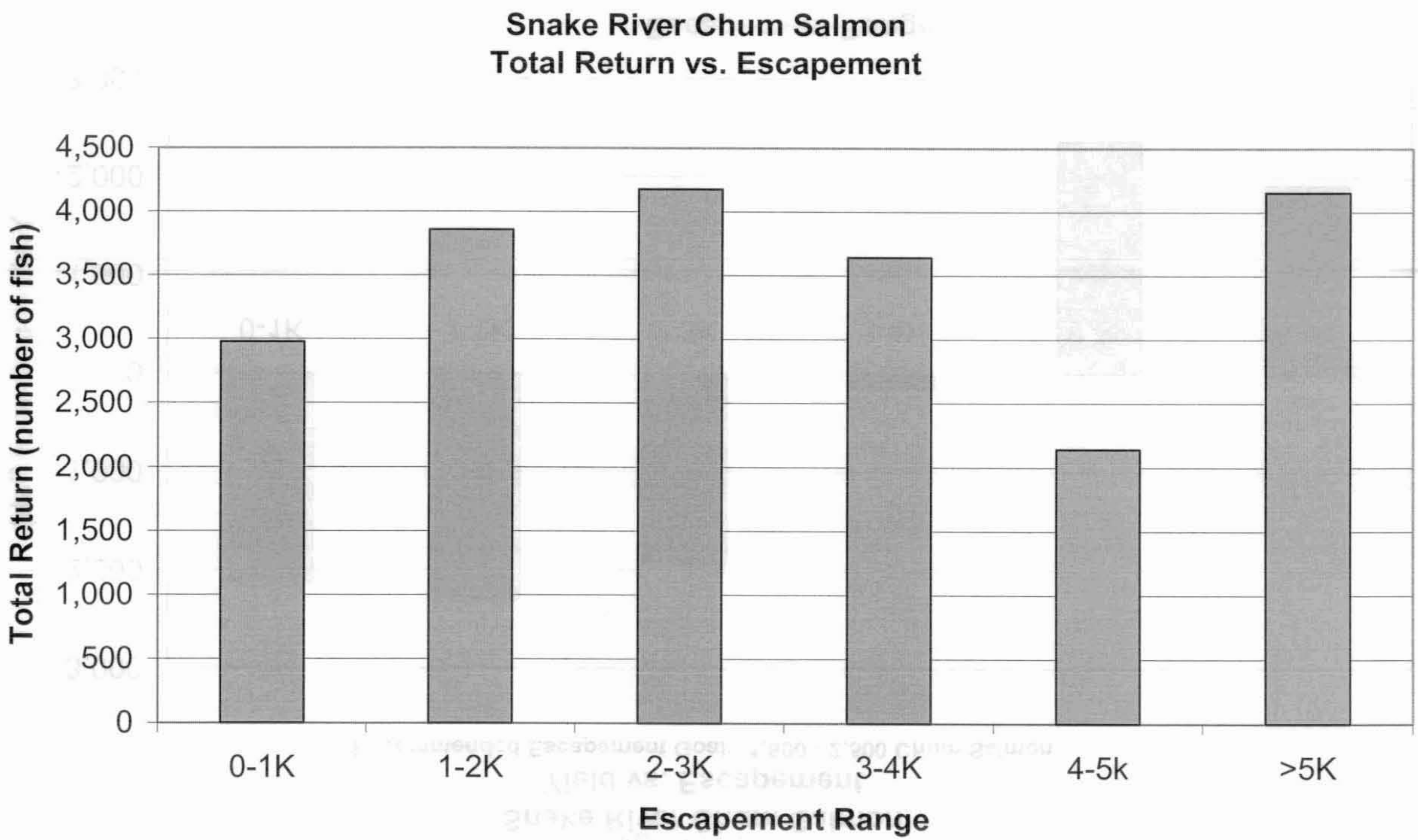

Figure A-5. Average return to the Snake River for an escapement range.

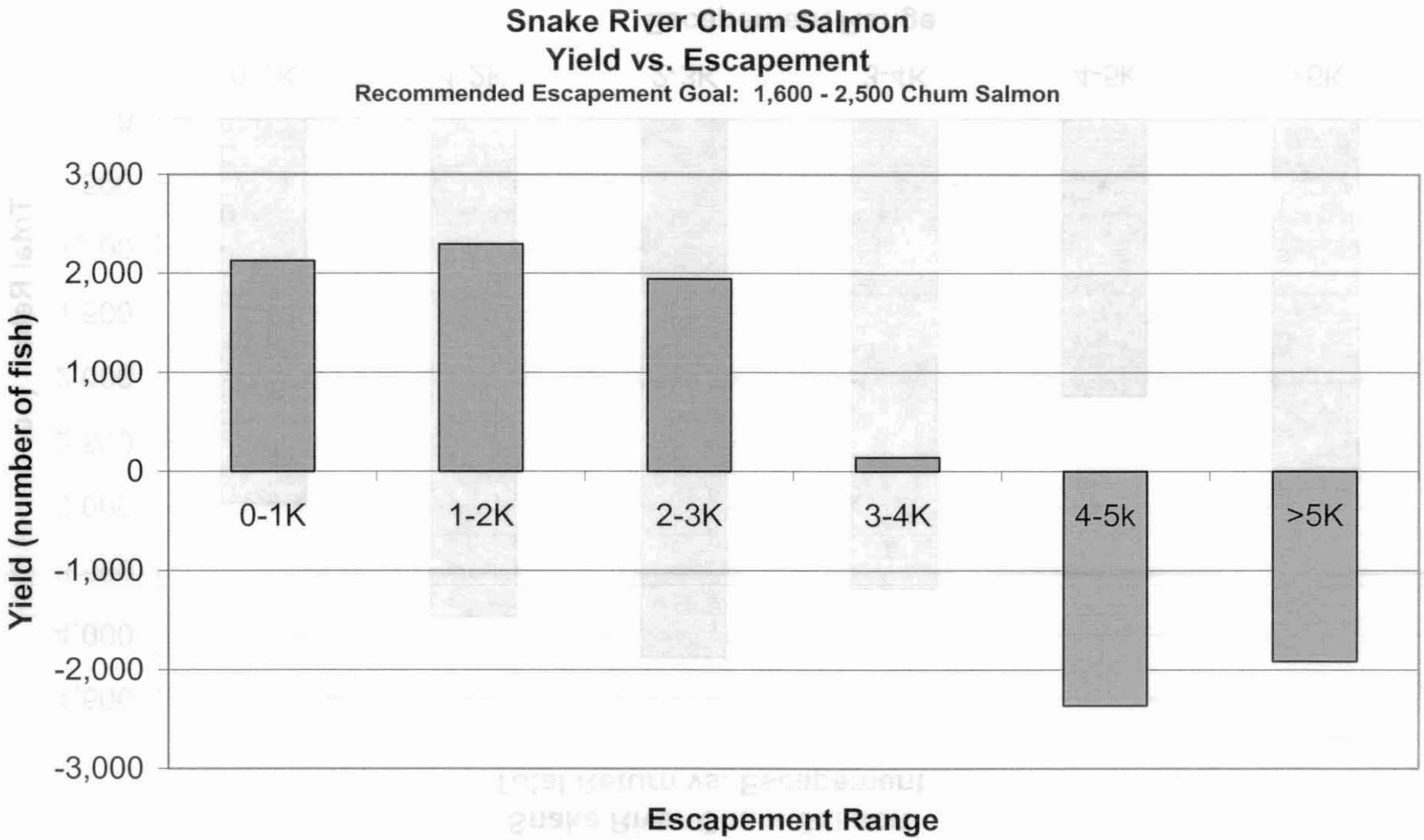

Figure A-6. Average yield for the Snake River for an escapement range.

Table A-4. Nome River chum salmon escapement, return, and yield in numbers of fish, 1975-1995.

Year	Escapement	Return	Yield	Escapement Range	Average Escapement	Average Return	Average Yield	Number of Observations
1983	1,552	5,838	4,286	0-2.5K	1,699	7,917	6,218	3
1976	1,621	12,790	11,169	2.5-5.0K	3,671	5,621	1,949	7
1989	1,923	5,123	3,200	5.0-7.5K	6,197	5,313	-885	7
1994	2,893	1,275	-1,618	>7.5K	12,572	5,453	-7,119	4
1990	3,005	4,475	1,470					
1979	3,213	5,669	2,456					
1982	3,560	7,032	3,472					
1988	4,165	6,854	2,689					
1986	4,260	7,037	2,777					
1981	4,603	7,002	2,399					
1995	5,092	2,573	-2,519					
1992	5,325	4,925	-400					
1993	5,925	3,529	-2,396					
1985	6,040	2,595	-3,445					
1987	6,243	9,061	2,818					
1984	7,291	3,209	-4,082					
1975	7,466	11,298	3,832					
1977	9,356	5,531	-3,825					
1991	10,289	4,757	-5,532					
1978	13,366	3,947	-9,419					
1980	17,275	7,577	-9,698					

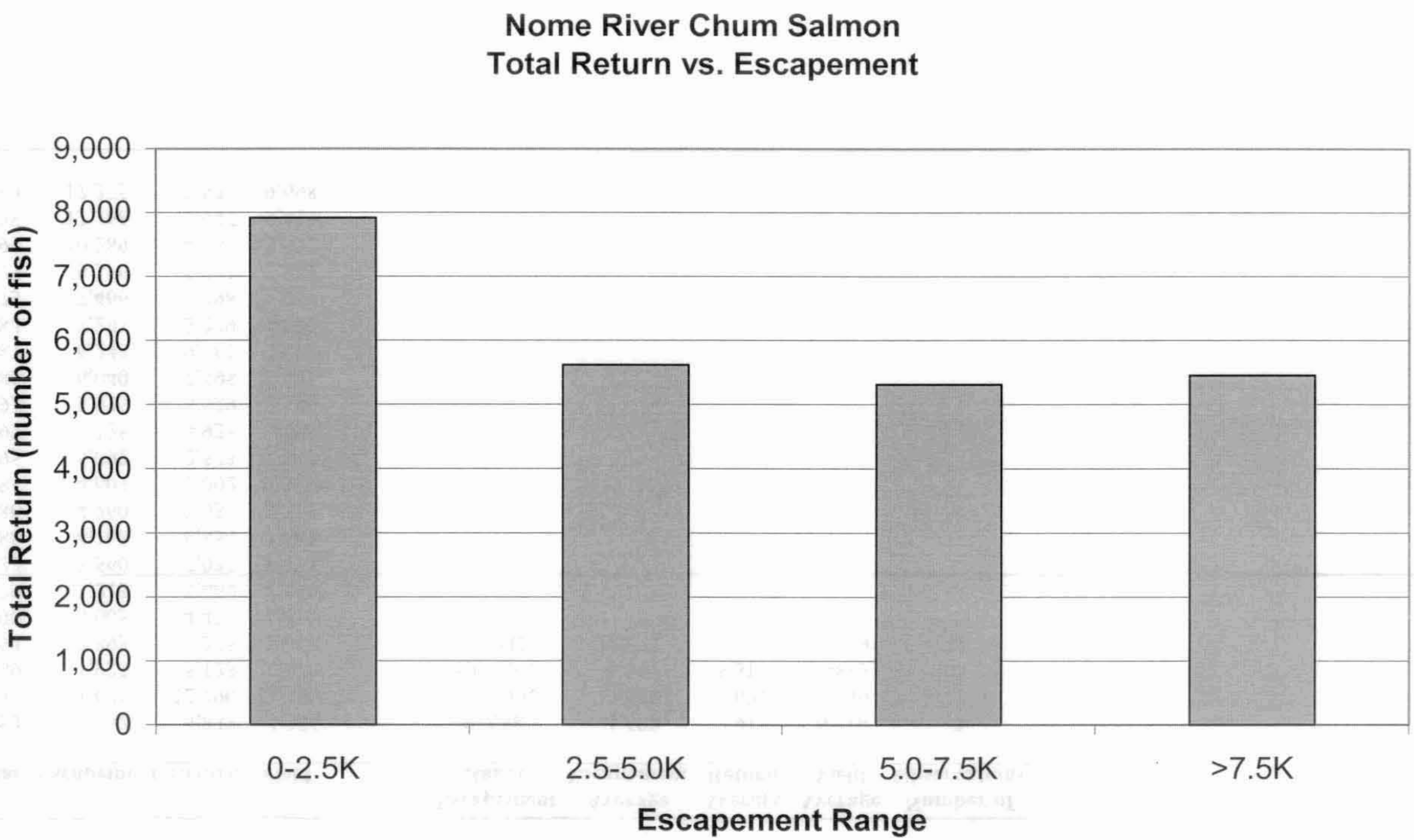

Figure A-7. Average return to the Nome River for an escapement range.

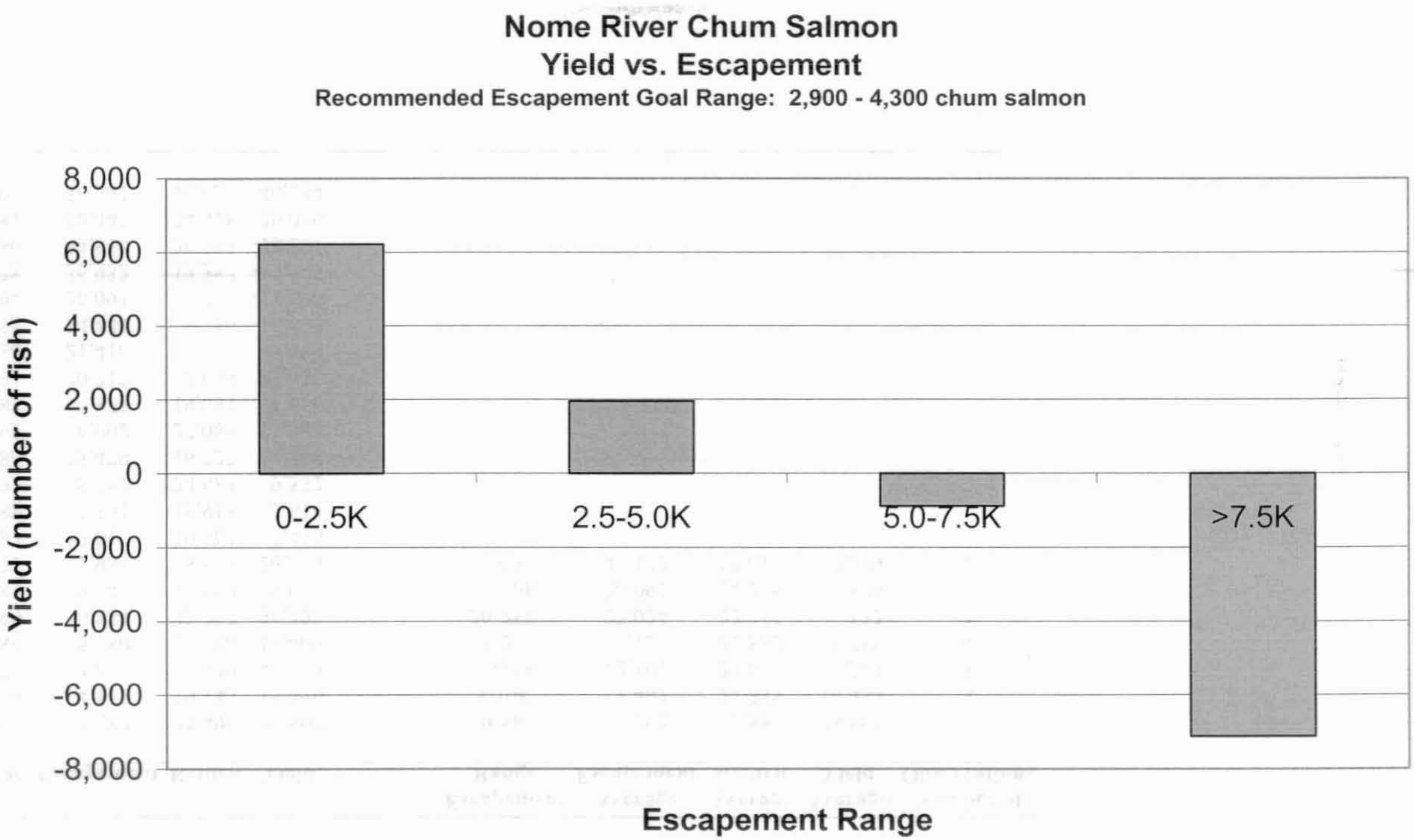

Figure A-8. Average yield for the Nome River for an escapement range.

Table A-5. Eldorado-Flambeau Rivers chum salmon escapement, return, and yield in numbers of fish, 1975-1995.

Year	Escapement	Return	Yield
1975	3,887	27,496	23,609
1979	4,117	19,143	15,026
1976	4,871	51,920	47,049
1989	5,780	21,180	15,400
1990	6,884	43,287	36,403
1983	9,541	17,599	8,058
1977	11,985	38,555	26,570
1987	12,017	19,463	7,446
1988	12,301	15,915	3,614
1993	15,151	24,683	9,532
1986	15,479	16,727	1,248
1992	16,002	27,085	11,083
1982	17,875	19,031	1,156
1991	20,217	44,039	23,822
1984	21,410	13,271	-8,139
1985	24,444	9,756	-14,688
1994	26,091	14,215	-11,876
1978	36,932	17,387	-19,545
1980	44,810	26,583	-18,227
1981	50,447	24,428	-26,019
1995	56,341	10,057	-46,284

Escapement Range	Average Escapement	Average Return	Average Yield	Number of Observations
0-5K	4,292	32,853	28,561	3
5-10K	7,402	27,355	19,954	3
10-15K	12,101	24,644	12,543	3
15-20K	16,127	21,882	5,755	4
20-25K	22,024	22,355	332	3
25-30K	26,091	14,215	-11,876	1
>30K	47,133	19,614	-27,519	4

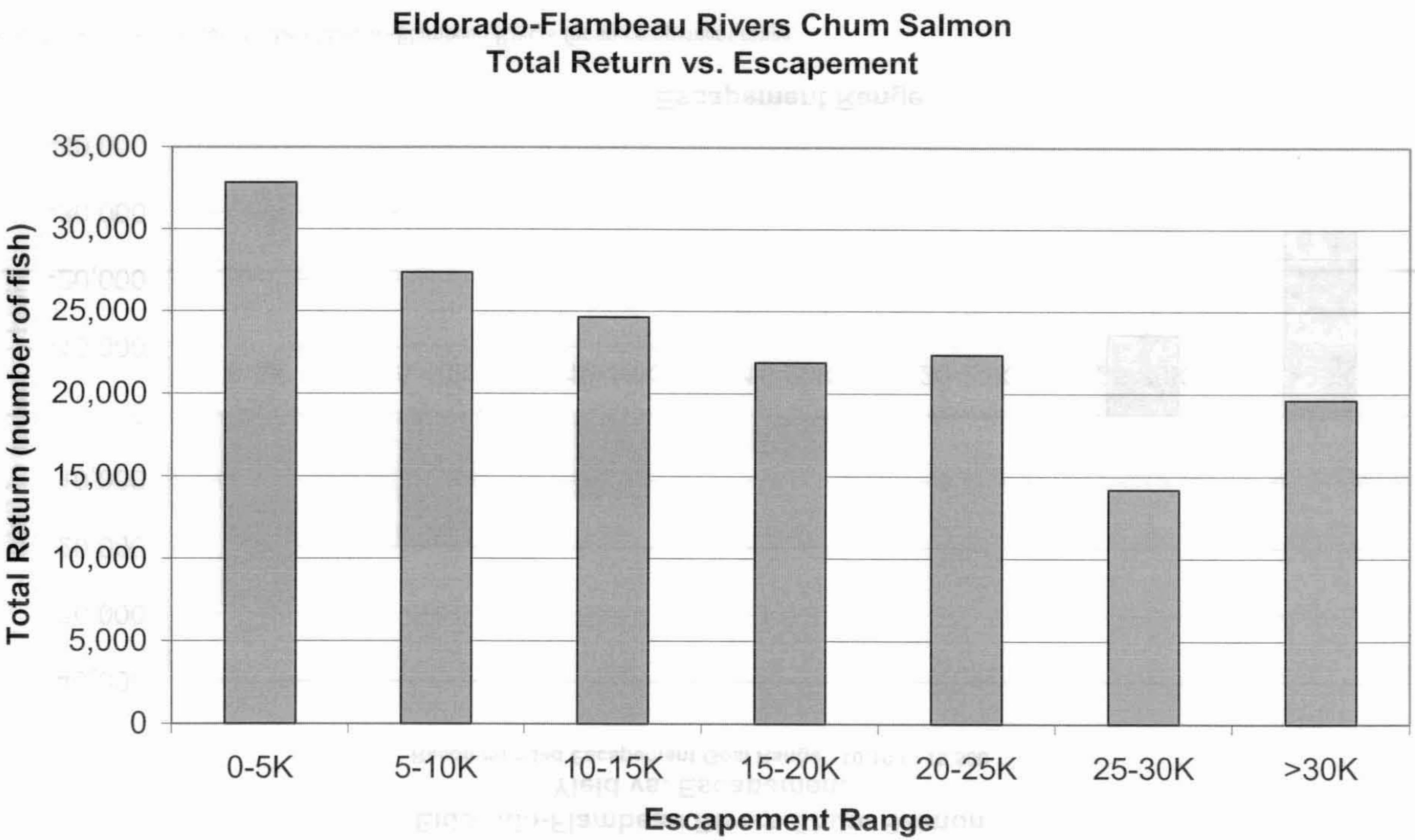

Figure A-9. Average return to the Eldorado-Flambeau Rivers for an escapement range.

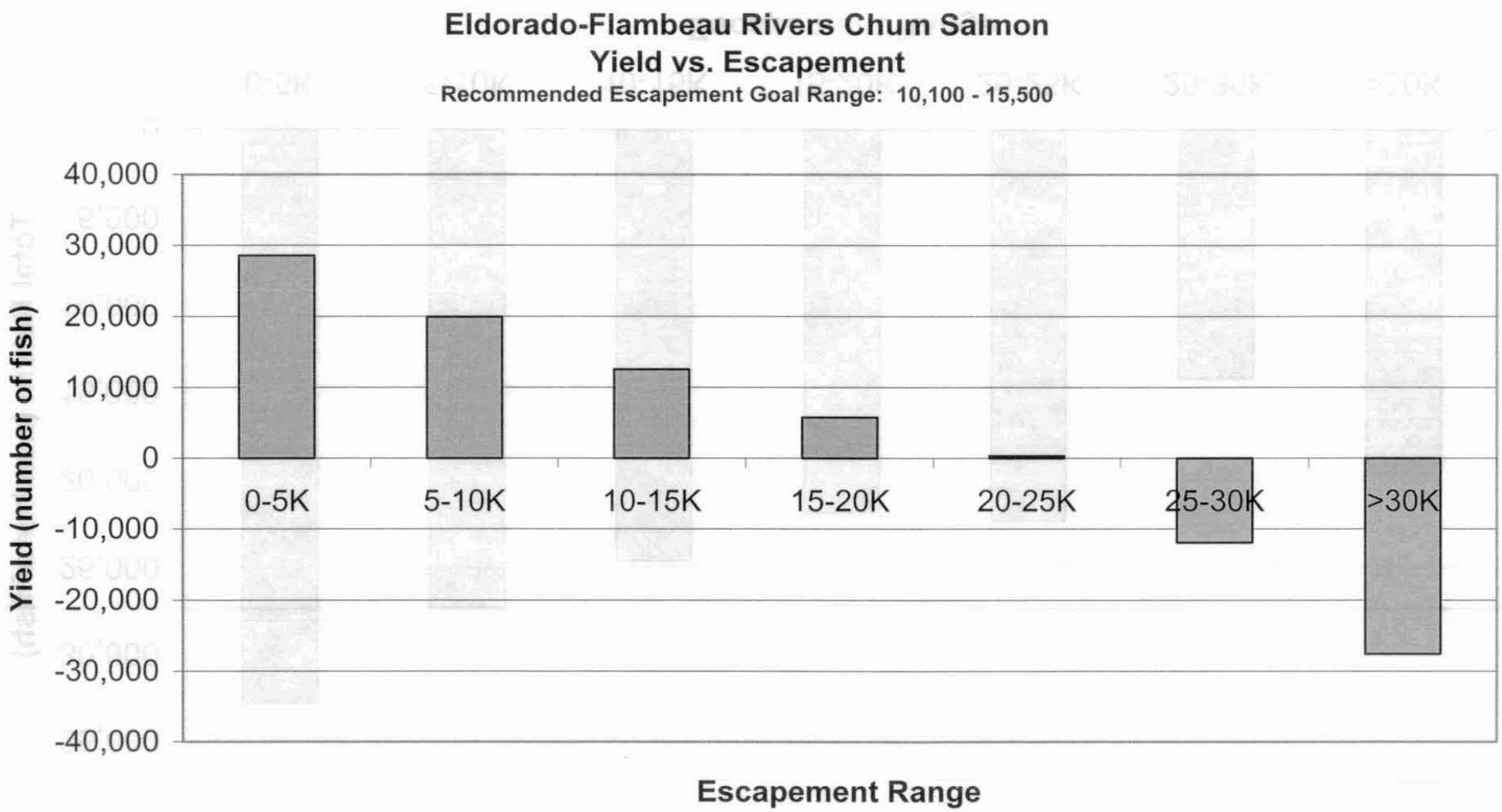

Figure A-10. Average yield to the Eldorado-Flambeau Rivers for an escapement range.

APPENDIX B

"GOOD" ESCAPEMENT SURVEY UNITS OF MEASURE–RICKER ANALYSIS

The information included in this appendix was prepared by Gene Sandone (Regional Supervisor, Arctic-Yukon-Kuskokwim Region, Commercial Fisheries Division, Alaska Department of Fish and Game) and was distributed via e-mail as an EXCEL spreadsheet to the Arctic-Yukon-Kuskokwim Biological Escapement Goal Committee on January 15, 2001. The analysis is a Ricker-type stock-recruit approach, however, the development of annual escapements and total return estimates were done in a different manner than those listed in the main text of this report. Specifically, Gene Sandone took the following approaches to development of the stock-recruit data set:

1. The analysis is directed at an escapement goal for chum salmon returning to Subdistrict One of Norton Sound and uses as basic building blocks for the annual Subdistrict One escapement, the summed survey counts of chum salmon spawning in nine streams of Norton Sound. Those streams are the Sinuk, Nome, Bonanza, Snake, Solomon, Flambeau, Eldorado, Penny, and Cripple Rivers.

2. The analysis is based upon survey data exclusively. In situations where total estimates by weir were available, those estimates were not used; instead, surveys were used if conducted for that stream in that year.

3. The units are not total chum salmon, but instead are in "good" survey units. "Good" survey units are those listed as a "1" in the Norton Sound stream catalogue. In cases where the survey rating was listed in the catalogue as other than a "1", counts were adjusted to survey rating "1" units based upon two assumptions. The first assumption was used for surveys with ratings listed as a "2". It is assumed that the surveyor only observed 75% of what he or she would have if conditions would have been rated as a "1". The second assumption was used for surveys with ratings listed as a "3". It is assumed that the surveyor only observed 50% of what he or she would have if conditions would have been rated as a "1".

4. In years when a specific stream was not successfully surveyed, the escapement was assumed to represent a standard percentage of the total Subdistrict One of Norton Sound chum salmon escapement. Assumed percentages used for all years in the analysis were: (1) Sinuk River: 17%; (2) Nome River: 12%; (3) Bonanza River: 10%; (4) Snake River: 7%; (5) Solomon River: 4%; (6) Flambeau River: 19%; (7) Eldorado River: 26%; (8) Penny River: 2%; and (9) Cripple River: 3%. These assumed proportions are all about the same as those provided in Table 27 of the main text.

5. The annual commercial and subsistence catches of chum salmon in Subdistrict One of Norton Sound were converted into "good" survey units based upon the inverse of equation 2 given in the main text of this report.

6. Age composition of total returns was assumed 50% age-4 and 50% age-5 fish, similar to the assumption used in the main text of this report.

7. Once the stock-recruit data base was developed as described above, Ricker type stock-recruit analysis, primarily as described earlier in the main text was used to estimate the escapement

predicted to produce maximum sustained yields to fisheries in Subdistrict One of Norton Sound using three time series. The three time series were: (1) brood years 1974-1995, (2) brood years 1980-1995, and (3) brood years 1983-1995.

Tables B-1 through B-12 and Figure B-1 provide a summary of the results from this analysis. However, it should be noted that residuals in these relationships were not tested for auto-correlation. Simple visual inspection of raw residuals (Table B-10) indicates that trends appear among the residuals rather than the random pattern one would want in residuals when developing stock-recruit relationships.

Table B-1. Sinuk and Nome River chum salmon escapement survey counts, ratings, and expanded counts (surveys with a rating of 1 are not expanded; surveys with a rating of 2 are expanded by a factor of 1.333; and, surveys with a rating of 3 are expanded by a factor of 2.000).

	Sinuk River Chum Salmon			Nome River Chum Salmon		
Year	Survey Count	Survey Rating	Expanded Survey	Survey Count	Survey Rating	Expanded Survey
1974	463	1	463	854	2	1,139
1975	4,662	1	4,662	2,161	2	2,881
1976						
1977	5,207	1	5,207	3,046	1	3,046
1978	8,756	1	8,756	5,242	1	5,242
1979						
1980	2,022	1	2,022	7,745	1	7,745
1981	5,579	1	5,579	1,035	1	1,035
1982	638	1	638	700	1	700
1983	2,150	1	2,150	198	1	198
1984	493	2	2,547	2,084	2	2,779
1985	1,910	2	1,960	1,565	1	1,565
1986	1,960	1	1,960	920	1	920
1987	4,540	1	4,540	1,646	1	1,646
1988	2,070	1	2,070	889	1	889
1989						
1990	95	2	127	541	2	721
1991	5,420	1	5,420	3,520	1	3,520
1992	470	3	940	180	1	180
1993	1,570	1	1,570	1,520	1	1,520
1994	1,140	1	1,140	345	1	345
1995	3,100	1	3,100	1,865	1	1,865
1996	1,815	1	1,815	799	1	799
1997	2,975	2	3,967	956	2	1,275
1998	630	2	840	335	2	447
1999	1,697	2	2,263	375	2	500
2000	10	1	10	658	2	877

Table B-2. Bonanza and Snake River chum salmon escapement survey counts, ratings, and expanded counts (surveys with a rating of 1 are not expanded and surveys with a rating of 2 are expanded by a factor of 1.333).

	Bonanza River Chum Salmon			Snake River Chum Salmon		
Year	Survey Count	Survey Rating	Expanded Survey	Survey Count	Survey Rating	Expanded Survey
1974	820	1	820			
1975	124	2	165			
1976	681	1	681			
1977	990	1	990	366	1	366
1978	5,984	1	5,984	255	1	255
1979	102	1	102			
1980	748	2	997			
1981	1,864	1	1,864	140	2	187
1982	380	1	380			
1983	723	1	723			
1984						
1985	775	1	775	1,100	1	1,100
1986				415	1	415
1987	190	2	253	267	1	267
1988						
1989						
1990						
1991	1,520	1	1,520	772	1	772
1992	80	1	80	943	1	943
1993				317	1	317
1994				688	1	688
1995				14	2	19
1996	1,980	1	1,980	405	1	405
1997	881	1	881			
1998				2,057	2	2,743
1999	361	2	481	400	1	400
2000	1,130	2	1,507			

Table B-3. Solomon and Flambeau River chum salmon escapement survey counts, ratings, and expanded counts (surveys with a rating of 1 are not expanded; surveys with a rating of 2 are expanded by a factor of 1.333; and, surveys with a rating of 3 are expanded by a factor of 2.000).

	Solomon River Chum Salmon			Flambeau River Chum Salmon		
Year	**Survey Count**	**Survey Rating**	**Expanded Survey**	**Survey Count**	**Survey Rating**	**Expanded Survey**
1974	160	1	160	190	1	190
1975				197	2	263
1976				375	1	375
1977	275	1	275	1,275	1	1,275
1978	497	1	497	7,110	1	7,110
1979	131	1	131	283	1	283
1980	2,600	1	2,600	13,190	1	13,190
1981				12,031	1	12,031
1982	487	1	487	5,083	1	5,083
1983	310	1	310	1,195	1	1,195
1984				3,150	1	3,150
1985	530	1	530	3,215	1	3,215
1986	165	1	165	3,075	1	3,075
1987	135	1	135	115	2	153
1988	25	1	25	765	1	765
1989	60	2	80			
1990	31	2	41			
1991	830	1	830	1,564	1	1,564
1992	25	1	25	606	1	606
1993	415	1	415	1,590	1	1,590
1994				4,960	1	4,960
1995	315	1	315	7,205	1	7,205
1996	323	1	323	5,390	1	5,390
1997	316	1	316	905	2	1,207
1998	90	2	120			
1999	51	2	68	51	3	102
2000	150	2	200	819	3	1,638

Table B-4. Eldorado and Penny River chum salmon escapement survey counts, ratings, and expanded counts (surveys with a rating of 1 are not expanded; surveys with a rating of 2 are expanded by a factor of 1.333; and, surveys with a rating of 3 are expanded by a factor of 2.000).

	Eldorado River Chum Salmon			**Penny River Chum Salmon**		
Year	**Survey Count**	**Survey Rating**	**Expanded Survey**	**Survey Count**	**Survey Rating**	**Expanded Survey**
1974	2,143	1	2,143			
1975				249	1	249
1976	411	2	548			
1977	1,835	1	1,835			
1978	10,125	1	10,125			
1979	326	2	435			
1980	9,900	1	9,900			
1981	15,605	1	15,605			
1982	1,095	1	1,095	8	2	11
1983	994	1	994			
1984	4,362	1	4,362			
1985	6,090	1	6,090	90	1	90
1986	1,575	1	1,575	6	3	12
1987	3,860	1	3,860	60	1	60
1988	2,645	1	2,645			
1989	350	2	467			
1990	884	1	884			
1991	5,735	1	5,735			
1992	4,887	1	4,887			
1993	2,895	1	2,895			
1994	5,144	1	5,144			
1995	9,025	1	9,025	15	3	30
1996	20,710	1	20,710			
1997	5,967	1	5,967			
1998				43	2	57
1999	1,741	2	2,321	15	3	30
2000	3,383	2	4,511			

Table B-5. Cripple River chum salmon escapement survey counts, ratings, and expanded counts (surveys with a rating of 1 are not expanded and surveys with a rating of 3 are expanded by a factor of 2.000).

Year	Survey Count	Survey Rating	Expanded Survey
1974			
1975			
1976			
1977			
1978			
1979			
1980			
1981			
1982			
1983	25	1	25
1984			
1985	180	1	180
1986	130	1	130
1987	68	1	68
1988			
1989			
1990			
1991	2,090	1	2,090
1992			
1993			
1994			
1995			
1996			
1997	105	1	105
1998			
1999	200	3	600
2000			

Table B-6. Estimated annual total escapement of chum salmon in Subdistrict One of Norton Sound expressed in "good" ("1") aerial survey units.

Year	Total Documented Escapement (simple sum of observed survey counts of chum salmon in nine Subdistrict One streams)	Assumed Proportion of Norton Sound Escapements Observed (see footnote below table for assumed proportions)	Documented Escapement Expanded for Survey Conditions (see Tables B-1 to B-5 for details for individual streams)	Total Estimated Escapement (documented escapement expanded for both survey ratings and observed proportions)
1974	4,630	0.89	4,915	5,552
1975	7,393	0.60	8,220	13,801
1976	1,467	0.55	1,604	2,935
1977	12,994	0.96	12,994	13,588
1978	37,969	0.96	37,969	39,705
1979	842	0.59	951	1,611
1980	36,205	0.89	36,454	41,180
1981	36,254	0.91	36,301	39,779
1982	8,391	0.90	8,394	9,309
1983	5,595	0.91	5,595	6,131
1984	10,089	0.74	10,948	14,732
1985	15,455	1.00	16,092	16,092
1986	8,246	0.90	8,252	9,152
1987	10,881	1.00	10,983	10,983
1988	6,394	0.79	6,394	8,126
1989	410	0.31	547	1,786
1990	1,551	0.60	1,773	2,950
1991	21,451	0.98	21,451	21,809
1992	7,191	0.96	7,661	8,011
1993	8,307	0.86	8,307	9,683
1994	12,277	0.81	12,277	15,078
1995	21,539	0.87	21,559	24,658
1996	31,422	0.96	31,422	32,858
1997	12,105	0.91	13,717	15,031
1998	3,155	0.43	4,207	9,869
1999	4,891	1.00	6,565	6,565
2000	6,150	0.93	8,743	9,411

Note: Observed proportion of escapement (column 3) was calculated by adding together an assumed proportion that was associated for each stream that was successfully surveyed in a given year. The assumed proportions used for all years in this analysis were: (1) Sinuk River: 17%; (2) Nome River: 12%; (3) Bonanza River: 10%; (4) Snake River: 7%; (5) Solomon River: 4%; (6) Flambeau River: 19%; (7) Eldorado River: 26%; (8) Penny River: 2%; and (9) Cripple River: 3%. These assumed proportions are all about the same as those provided in Table 27 of the main text.

Table B-7. Estimated annual total runs of chum salmon in Subdistrict One of Norton Sound expressed in "good" ("1") aerial survey units.

Year	Total Estimated Subsistence and Commercial Catch of Chum Salmon in Subdistrict One of Norton Sound	Total Catch of Chum Salmon Converted into "Good" Escapement Survey Units	Total Estimated Escapement (see column 5 in Table B-6) Expressed in "Good" Escapement Survey Units	Total Estimated Run of Chum Salmon to Subdistrict One of Norton Sound Expressed in "Good" Escapement Survey Units
1974	10,614	3,691	5,552	9,243
1975	11,222	4,017	13,801	17,818
1976	9,325	3,031	2,935	5,966
1977	28,190	16,318	13,588	29,906
1978	13,077	5,070	39,705	44,775
1979	8,664	2,710	1,611	4,321
1980	19,905	9,609	41,180	50,789
1981	27,245	15,493	39,779	55,271
1982	18,278	8,440	9,309	17,749
1983	18,782	8,796	6,131	14,927
1984	8,627	2,692	14,732	17,424
1985	11,886	4,385	16,092	20,476
1986	16,245	7,053	9,152	16,206
1987	14,040	5,649	10,983	16,632
1988	7,580	2,211	8,126	10,337
1989	3,891	802	1,786	2,588
1990	4,246	915	2,950	3,866
1991	3,715	747	21,809	22,556
1992	2,565	425	8,011	8,436
1993	1,898	269	9,683	9,952
1994	1,739	235	15,078	15,314
1995	5,466	1,344	24,658	26,002
1996	4,336	945	32,858	33,804
1997	4,996	1,173	15,031	16,204
1998	964	96	9,869	9,965
1999	337	19	6,565	6,585
2000	651	53	9,411	9,464

Table B-8. Estimated recruits from chum salmon escapements in Subdistrict One of Norton Sound expressed in "Good" escapement survey units.

Year	Total Estimated Escapement Expressed in "Good" Escapement Survey Units	Total Estimated Run Expressed in "Good" Escapement Survey Units	Estim-Ated Exploit-ation Rate	Estimated Age-4 Recruits Expressed in "Good" Escapement Survey Units	Estimated Age-5 Recruits Expressed in "Good" Escapement Survey Units	Estimated Total Recruits Expressed in "Good" Escapement Survey Units
1974	5,552	9,243	40%	22,388	2,160	24,548
1975	13,801	17,818	23%	2,160	25,394	27,555
1976	2,935	5,966	51%	25,394	27,636	53,030
1977	13,588	29,906	55%	27,636	8,875	36,510
1978	39,705	44,775	11%	8,875	7,464	16,338
1979	1,611	4,321	63%	7,464	8,712	16,176
1980	41,180	50,789	19%	8,712	10,238	18,950
1981	39,779	55,271	28%	10,238	8,103	18,341
1982	9,309	17,749	48%	8,103	8,316	16,419
1983	6,131	14,927	59%	8,316	5,168	13,484
1984	14,732	17,424	15%	5,168	1,294	6,462
1985	16,092	20,476	21%	1,294	1,933	3,227
1986	9,152	16,206	44%	1,933	11,278	13,211
1987	10,983	16,632	34%	11,278	4,218	15,496
1988	8,126	10,337	21%	4,218	4,976	9,194
1989	1,786	2,588	31%	4,976	7,657	12,633
1990	2,950	3,866	24%	7,657	13,001	20,658
1991	21,809	22,556	3%	13,001	16,902	29,903
1992	8,011	8,436	5%	16,902	8,102	25,004
1993	9,683	9,952	3%	8,102	4,983	13,085
1994	15,078	15,314	2%	4,983	3,292	8,275
1995	24,658	26,002	5%	3,292	4,732	8,024
1996	32,858	33,804	3%	4,732	-	-
1997	15,031	16,204	7%			
1998	9,869	9,965	1%			
1999	6,565	6,585	0%			
2000	9,411	9,464	1%			

Table B-9. Stock-recruitment relationship statistics for the chum salmon population that returns to Subdistrict One of Norton Sound when both escapements and recruits are expressed in "Good" escapement survey units.

Stock-Recruit Relationship Statistic	District One of Norton Sound Chum Salmon Brood Years 1974-1995	District One of Norton Sound Chum Salmon Brood Years 1980-1995	District One of Norton Sound Chum Salmon Brood Years 1983-1995
Adjusted Ricker Alpha	6.2684	3.8397	6.8759
Ricker Beta	-0.000072	-0.000006	-0.000126
Significance of Relationship	0.00013	0.00386	0.00143
Number of Brood Years	22	16	12
MSY Escapement Level	9,442	9,070	5,598

Table B-10. Residuals associated with the three stock recruit curves developed in units of "good" escapement survey units.

Brood Year	1974-1995 Residuals	1980-1995 Residuals	1983-1995 Residuals
1974	0.41057		
1975	0.21126		
1976	1.62915		
1977	0.49284		
1978	0.50263		
1979	0.94619		
1980	0.72098	0.6679	
1981	0.62173	0.5854	
1982	-0.23715	0.0928	
1983	-0.24593	0.1223	-0.12434
1984	-1.23696	-0.9721	-0.65524
1985	-1.92156	-1.6730	-1.26708
1986	-0.44889	-0.1169	-0.16566
1987	-0.33946	-0.0295	0.04169
1988	-0.76653	-0.4222	-0.53823
1989	0.60819	1.0286	0.49735
1990	0.68241	1.0889	0.63383
1991	0.41378	0.5935	1.37411
1992	0.23986	0.5855	0.46204
1993	-0.47651	-0.1509	-0.16490
1994	-0.98794	-0.7272	-0.38766
1995	-0.81872	-0.6731	0.29405

Table B-11. Comparison of the results of this analysis (Appendix B-brood year 1974-1995 analysis) to the survey escapement goals listed by Buklis (1993).

River	Escapement Proportion Assumption	Approximate River Specific Goal	Goal Listed in Buklis 1993	Comments
Sinuk	17%	1,600	4,500	About 35%
Nome	12%	1,100	2,000	About 55%
Bonanza	10%	950	1,500	About 63%
Snake	7%	670	1,000	About 67%
Solomon	4%	380	550	About 69%
Flambeau	19%	1,800	3,250	About 55%
Eldorado	26%	2,500	5,250	About 48%
Penny	2%	200	None	-
Cripple	3%	300	None	-
Totals	**100%**	**9,500**	**18,050**	**About 53%**

Table B-12. Comparison of the results of this analysis (Appendix B-brood year 1974-1995 analysis) to the analysis provided in the main text (see recommendations section).

River	Approximate River Specific Goal	Expansion of Survey Goal to Total Escapement (Formula 2 in Main Text applied to 9,500)	Escapement Goal Range in Recommendations Section of Main Text	Comments
Sinuk	1,600	3,400	4,000 to 6,200	Below lower range
Nome	1,100	2,400	2,900 to 4,300	Below lower range
Bonanza	950	2,000	2,300 to 3,400	Below lower range
Snake	670	1,400	1,600 to 2,500	Below lower range
Solomon	380	800	1,100 to 1,600	Below lower range
Flambeau	1,800	3,800	4,100 to 6,300	Below lower range
Eldorado	2,500	5,200	6,000 to 9,200	Below lower range
Penny	200	400	400 to 600	At lower range
Cripple	300	600	600 to 900	At lower range
Totals	**9,500**	**20,000**	**23,000 to 35,000**	**Below lower range**

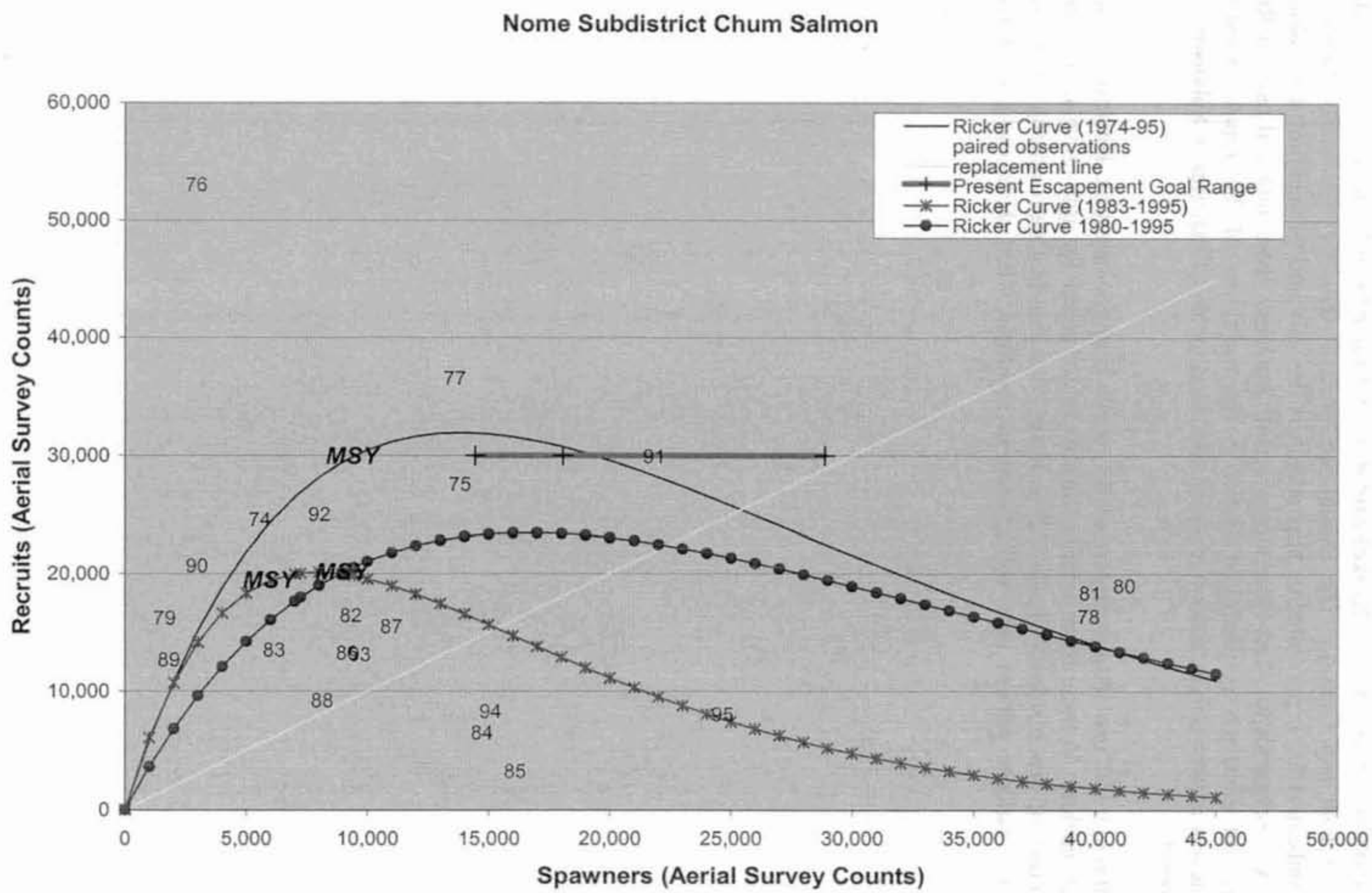

Figure B-1. Stock-recruit curves for chum salmon runs to Subdistrict One of Norton Sound given three alternate time frames with units of measure being "Good" escapement survey counts.

APPENDIX C

RICKER ANALYSIS SPECIFIC TO THE NOME, SNAKE, AND FLAMBEAU-ELDORADO RIVERS

The annual stock-recruit data sets included in this appendix were prepared by Gene Sandone (Regional Supervisor, Arctic-Yukon-Kuskokwim Region, Commercial Fisheries Division, Alaska Department of Fish and Game). The annual stock-recruit data for the Snake, Nome, and Eldorado-Flambeau rivers is presented in Appendix A in the left-hand three columns of Tables A-3, A-4, and A-5, respectively. The three stock-recruit data-bases were analyzed using a Ricker type stock-recruit approach as described earlier in the main text of this report to estimate escapement levels expected to produce maximum sustained yields to fisheries in Subdistrict One of Norton Sound.

Tables C-1 through C-3 provide a summary of the results from this analysis. However, it should be noted that residuals in these three relationships were not tested for auto-correlation. Simple visual inspection of raw residuals (Table C2) indicates that trends appear among the residuals rather than the random pattern one would want in residuals when developing stock-recruit relationships.

Table C-1. Stock-recruit relationship statistics for the chum salmon populations that return to the Snake, Nome, and Eldorado-Flambeau rivers of Norton Sound.

Stock-Recruit Relationship Statistic	**Snake River Chum Salmon Brood Years 1975-1995**	**Nome River Chum Salmon Brood Years 1975-1995**	**Eldorado-Flambeau Chum Salmon Brood Years 1975-1995**
Adjusted Ricker Alpha	5.21253	3.11453	5.55936
Ricker Beta	-0.00043	-0.00015	-0.000059
Significance of Relationship	0.000072	0.000674	0.0000012
Number of Brood Years	21	21	21
MSY Escapement Level	1,499	3,254	11,008
Estimated Max. Sustained Yield	2,633	3,012	20,812
Est. MSY Exploitation Rate	64%	48%	65%

Table C-2. Residuals associated with the stock recruit curves developed for the Snake, Nome, and Eldorado-Flambeau chum salmon populations of Norton Sound.

Brood Year	**Snake Residuals**	**Nome Residuals**	**Eldorado - Flambeau Residuals**
1975	-867	3,581	10,343
1976	2,642	8,817	31,645
1977	135	-1,783	5,865
1978	-1,617	-1,831	-5,494
1979	-40	-556	1,221
1980	2,006	3,385	9,198
1981	1,501	-261	10,426
1982	-2,164	479	-15,328
1983	-2,333	1,995	-12,492
1984	-2,732	-4,524	-20,087
1985	-2,261	-5,112	-22,047
1986	-2,031	-34	-17,579
1987	-303	1,330	-13,252
1988	-1,106	-157	-17,013
1989	-177	615	-1,614
1990	458	-1,529	17,863
1991	-354	-2,251	10,226
1992	896	-2,627	-7,295
1993	4,147	-4,161	-9,556
1994	1,687	-4,601	-6,567
1995	-2,584	-4,901	-961

Table C-3. Comparison of the results of this analysis (Appendix B-brood year 1974-1995 analysis) to the analysis provided in the main text (see recommendations section).

River	Estimated MSY Escapement Level (total fish)	Escapement Goal Range in Recommendations Section of Main Text	Comments
Nome	3,254	2,900 to 4,300	In recommended range
Snake	1,499	1,600 to 2,500	Below recommended range
Eldorado/ Flambeau	11,008	10,100 to 15,500	In recommended range